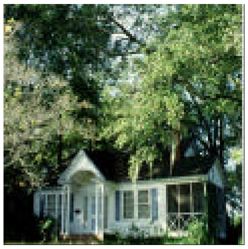
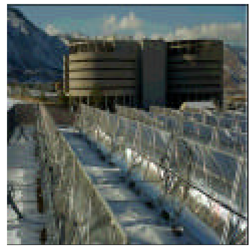
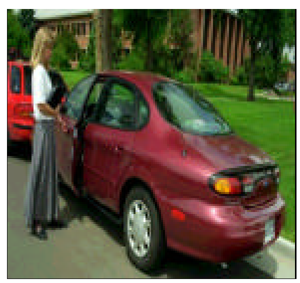




Renewable Energy:

A Guide to the New World of Energy Choices


NREL

National Renewable Energy Laboratory

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Renewable Energy: A Guide to the New World of Energy Choices

What is Renewable Energy?

The United States relies heavily on coal, oil, and natural gas for its energy. Currently, coal fuels most of the electric power plants in this country, petroleum products fuel our cars, and oil and natural gas heat most of our buildings. U.S. industry depends on all these energy sources.

Coal, oil, and natural gas are all "fossil" fuels—they were formed millions or even hundreds of millions of years ago from decaying prehistoric plants and animals. Although fossil fuels are still being created today by underground heat and pressure, they are consumed much more rapidly than they are created. Fossil fuels are "nonrenewable," meaning that they draw on finite resources that will eventually dwindle, becoming too expensive or too environmentally damaging to retrieve. The search for new reserves of fossil fuels has already led to oil drilling along ocean coasts and other environmentally sensitive areas.

In contrast, "renewable energy" resources—such as wind and solar energy—are constantly replenished and will never run out. Most renewable energy comes either directly or indirectly from the sun.

Sunlight can be used directly for heating and lighting residential and commercial buildings. The heat of the sun can be harnessed for hot water heating, solar cooling, and other commercial and industrial uses. The sun's heat can also be used to generate electricity, using a technology called solar thermal electric power. Sunlight can also be converted directly to electricity using photovoltaic cells, also called solar cells.

Many other forms of renewable energy are indirectly powered by the sun. For instance, the sun's heat drives the winds, which produce energy that is captured with wind turbines. Winds, in turn, cause ocean waves, producing energy that can be converted to electricity. Sunlight also causes plants to grow—the energy stored in those plants is known as biomass energy. Biomass can be converted to liquid or gaseous fuels or burned to produce electricity. The sun's heat evaporates water that then forms the rain and snow that feed our rivers, which are tapped with hydroelectric power plants. The sun's heat also warms the surface of the ocean more than the ocean depths. This temperature difference can be used to produce power using a technology known as ocean thermal energy conversion.

But not all renewable energy resources come from the sun. Geothermal energy—heat from the Earth—is tapped for a variety of uses, including electric power production. And tides, caused by the moon's pull on the Earth's oceans, can also be harnessed for their power.

All these renewable energy resources—solar, wind, biomass, hydroelectric, ocean, and geothermal energy—are inexhaustible and offer many environmental benefits over conventional energy sources. Each type of renewable energy also has its own special advantages that make it uniquely suited to certain applications.

In this guide, we present a simple introduction to each of these renewable energy technologies. For each technology, we discuss the benefits of the technology and give examples of where and how it might be used. In addition, we cover the real-life applications of each technology.

Most of the technologies presented here are commercially available today, but their use is limited. This may be because of high costs or other factors, but sometimes it's simply because people aren't familiar with the technology. As you'll see, many renewable energy technologies are already well developed enough to be used in a variety of applications. These technologies, then, should be given serious consideration in any decision involving energy, from buying a new water heater to building a new power plant.

The U.S. Department of Energy is helping to advance the use of renewable energy by supporting research and development, by working with industry to build demonstration projects, and by publicizing the work through publications such as this.

Passive Solar Heating, Cooling, and Daylighting

A summer day at the beach is enough to convince anyone of the power of solar heating. Ancient civilizations were well aware of the sun's benefits, often designing their homes around the sun. For instance, the Anasazi Indians in the Southwest built their homes into south-facing cliffs to benefit from the heat of the winter sun. Yet standard home designs typically make very little use of this ample resource.

Today, more than 200,000 homes in the United States incorporate special design features that take advantage of the natural solar resource. Because these design features don't require pumps, fans, or other mechanical equipment, they are called "passive" solar designs. These solar homes cost only slightly more than standard homes, yet they save energy and actually make the home more comfortable.

As passive solar designs have evolved, an associated "toolbox" of techniques has been developed. Some such tools are ideal for helping to heat buildings in the winter, others help keep buildings cool in the summer, and still others help provide natural lighting, also called "daylighting." Many of the tools offer more than one benefit—for instance, windows can provide both passive solar heating and daylighting. Building designers can combine energy-efficient features, such as insulation, with these passive solar design tools to create the ideal house for any particular climate and location.

Although passive solar technologies can be sophisticated in design, they often appear quite simple. In fact, the most elegant passive solar technologies can be such an integral part of a building that a visitor may be totally unaware of the building's solar features.

Passive Solar Heating and Cooling

Because the south side of a building always receives the most sunlight, exposing that side to the sun is the key aspect of passive solar heating. Windows on the north, east, and west let in little winter sunlight and usually cause the building to lose more heat than it gains. All the passive solar heating design tools are intended to make the most of a building's southern exposure.

The most obvious tool is a building design featuring large south-facing windows. Materials that absorb and store heat can be built into floors and walls positioned to receive a lot of sunlight. These floors and walls will then heat up during the day and slowly release their heat at night, when the heat is needed most. This combination of features is called "direct gain."

Of course, this approach depends on the use of modern, insulating windows. Many windows in older homes let cool air in and let heat leak out of the house. Modern double-pane or triple-pane windows leak very little air and also insulate better than older windows. New "superwindows" are now being developed that will hold heat in as well as a wall. When used for direct gain, these superwindows will provide all the advantages of letting the sunlight in during the day plus holding the heat in at night.

Direct gain is only one of many tools for the passive solar designer—another is to construct a "sunspace" on the south side of the house. The floor of the sunspace will usually be a heavy tile or brick to absorb heat throughout the day, then release heat into the home at night. Vents can allow the heat to circulate into the home. On hot summer days, the sunspace can be closed off from the house, and windows in the top of the sunspace can be opened to let the hot air out. Sunspaces also serve as greenhouses for growing flowers and vegetables in the winter.

To be effective, sunspaces depend on proper air circulation. In a two-level home, the sunspace is attached so that the heated air rises in the sunspace and passes into the upper floor of the house. As the heated air cools, it sinks down to the first floor and flows back to the sunspace. In this way, heated air is continually circulated throughout the home. Designing for proper air circulation is an important aspect of all passive solar designs.

Another passive solar heating tool is the use of a very thick south-facing wall, called a "Trombe wall," which is painted black and made of a material that absorbs a great deal of heat. A pane of glass or plastic glazing, installed a few inches in front of the wall, helps hold in the heat. The wall heats slowly during the day and then gradually cools during the night, giving off its heat to the inside of the house.

This house in Longmont, Colorado won a Governor's award for energy efficiency. It has a south-facing Trombe wall design.

Of course, too much solar heating can be a problem during the hot summer months and in warm southern climates. Fortunately, many design tools can help keep solar houses cool in the summer—an approach called "passive cooling." For instance, window overhangs can be designed to let in the maximum amount of sunlight during the winter, when the sun is low in the sky. But in the summer, when the sun is high, the overhangs shade the windows.

The extended window overhangs on this employee housing unit in Yosemite National park help keep residents cool in the summer.

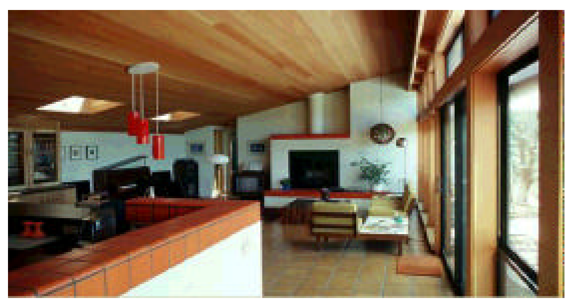
In hot climates, it's best to avoid skylights and windows on the east and west sides of the house—they let in the most heat in the summer but very little heat in the winter when it's needed. To help keep out the summer heat, trees, bushes, and vines can be used for shading on the east and west sides of the house.

Mature deciduous trees provide shade in the summer and sunlight filtration in the winter.

Natural ventilation is another passive cooling tool. Home designs that encourage hot-air circulation in the winter can also provide fresh-air ventilation in the summer.

Daylighting

We mentioned daylighting earlier—daylighting is simply using natural sunlight to brighten a building's interior. This can save much of the energy used for lighting during the day and can help keep buildings cool in the summer. Because many of the features used for passive solar heating and cooling also provide daylighting benefits, daylighting and passive solar heating and cooling work well together.



The Interior of this house in California demonstrates the daylighting element of passive solar design.

Large windows or a sunspace on the south side of a house usually light that section of the house very well, but lighting the north rooms and the upper level of the house can be more difficult. One common solution is to include a "clerestory"—a row of light-admitting windows near the peak of the roof—and use an open architecture inside the home to let the light bounce around in the house. Clerestories also provide additional passive solar heating and can be used to help ventilate the house in the summer.

The row of light-admitting windows near the ceiling of this atrium reduces utility costs.

Daylighting has its greatest value in large commercial buildings or office buildings. Most of these buildings are difficult to keep cool because of all the heat given off by machinery, office equipment, and people. Lights produce heat and add to the cooling problem, so daylighting can cut down on the energy needed for air conditioning. If less air conditioning is needed, the building can use a smaller air-conditioning system, which reduces the cost of the building.

Lighting is also a large part of the energy bill for commercial buildings. Because many of these buildings are used only during the daytime, daylighting can provide most of their lighting needs and save energy, both for lighting and cooling.

In large buildings, one approach to daylighting is a stepped building design with an open architecture inside. The stepped design allows sunlight to come in through many locations along the roof, rather than just through a window at the end of the building. Other features—such as reflective surfaces outside and surfaces to reflect and spread out the light inside—help to channel the light into the building. Some building designs even use mirrors to bounce the sunlight onto large textured surfaces that spread the light softly into the building. This approach works well in buildings with large interior spaces, such as shopping malls or large luxury hotels.

The Resource for Passive Solar Energy

Passive solar energy has applications throughout the country, but its design and application vary with location and climate. Good passive solar designs reach a balance between insulation to reduce heating needs and passive solar features to add more heat to the home. In hot climates, insulation is also important to help keep the home cool in the summer,

The Solar Energy Research Facility at the National Renewable Energy Laboratory is a good example of stepped building design.

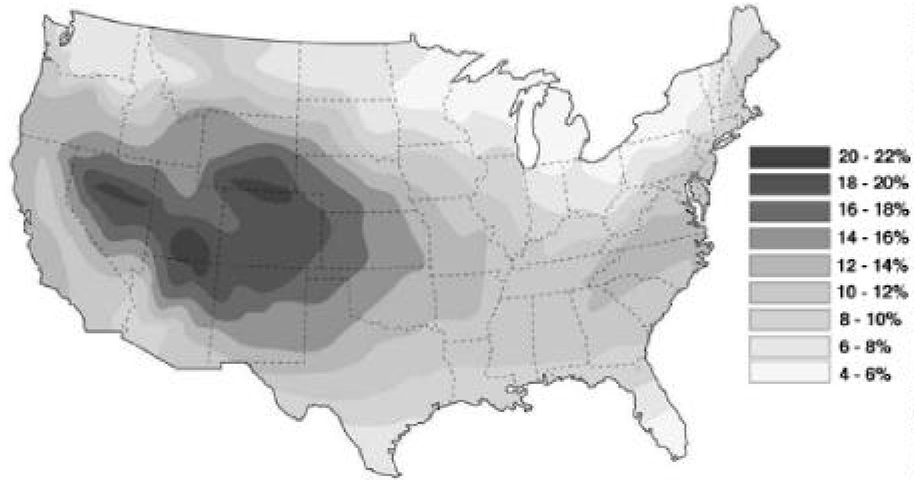
but features such as south-facing windows must be carefully sized and shaded to avoid overheating the home.

This difference is shown graphically in the top map on page 5. The map shows the area of passive solar features (for instance, the area of south-facing windows) for homes in the continental United States. The area is given as a percentage of the floor area, assuming that the home is appropriately insulated. For instance, a 2000-square-foot (186-square-meter) home in southern Texas should have south-facing windows with a combined area of 6–8 percent of the floor space, which is 120–160 square feet (11–15 square meters) of windows. The same size house in Colorado should have about 360–400 square feet (33–37 square meters) of south-facing windows—three times as much as the south Texas home.

Of course, the effectiveness of passive solar heating also varies throughout the country, based on the amount of sunlight available. The bottom map on page 5 shows the amount of home heating energy that could be saved each year using a typical direct-gain design. See the discussion in the box on page 6 to find out how to use the two maps to determine the ideal amount of solar heating in your area.

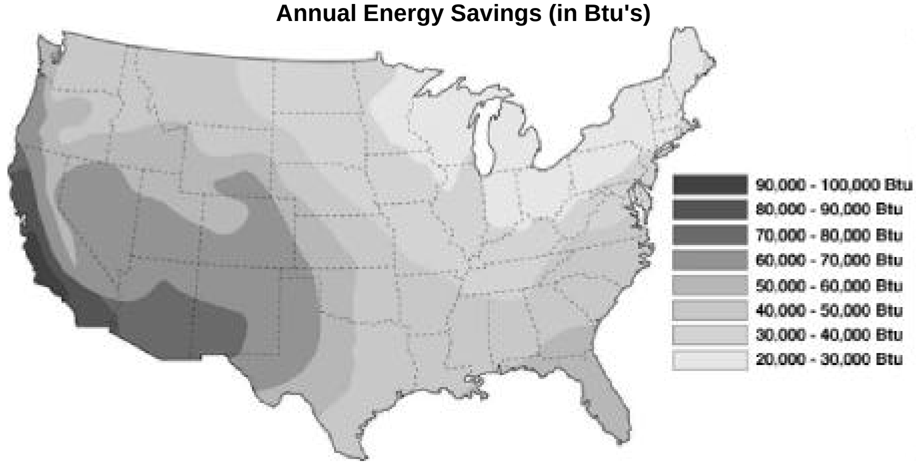
The example discussed in the box is a 2000-square-foot home in Kansas City, Missouri, which could save about 9.2 million to 14 million Btu (2800–4100 kilowatt-hours). For a home with a gas furnace that has an efficiency of 70 percent, that energy savings would be the equivalent of 13,000–19,000 cubic feet (370–540 cubic meters) of natural gas. Because the national average residential price for natural gas is

Recommended Area of Passive Solar Features



The recommended area of passive solar features (such as south-facing windows) for a home in the continental United States is shown here as a percentage of the home's floor area.

Annual Energy Savings (in Btu's)



Annual energy savings in Btu per square foot of passive solar features is shown here, using direct gain for the solar features

$6.34 per thousand cubic feet, the homeowner would save about $80–$120 per year on heating bills.

Solar Water Heating for Homes

Most swimmers know that the shallow edges of a lake are usually warmer than the deep water in the center. In the shallow areas, sunlight heats the lake bottom, which in turn heats the water. This is nature's way of solar water heating. Many homes now take advantage of this same basic principle to heat water used in the homes and to heat swimming pools.

The main element of solar water heating systems is the solar collector, which heats either water or another fluid, such as an antifreeze solution. The most common systems use a roof-mounted collector called a "flat-plate collector," which consists of a thin, flat, rectangular box with a transparent cover that faces the sun. Small tubes run through the box, carrying the fluid to be heated. The tubes are mounted on an "absorber plate," which is a plate of metal painted black to absorb the sun's heat, much as the lake bottom absorbs heat. The back and sides of the box are insulated to hold in the heat. Heat builds up in the collector, and the fluid is heated as it passes through the tubes.

The two maps can be used to determine how much energy could be saved in any location using a home with an ideal amount of solar heating. The *upper* map can be used to determine the ideal passive solar area for a house. The *lower* map shows energy savings in Btu per square foot of passive solar area, so it must be combined with the *upper* map to figure out the actual energy savings.

For instance, using the *upper* map, a home in Kansas City, Missouri, should have a solar area of 12–14 percent of its floor space. For a 2000-square-foot (186-square-meter) home, that percentage results in a solar area of 240–280 square feet (22–26 square meters):

Lowest solar area: 0.12 × 2000 square feet = 240 square feet
Highest solar area: 0.14 × 2000 square feet = 280 square feet

Referring to the energy-savings map, a home in Kansas City should save 40,000–50,000 Btu per square foot of solar area (126–158 kilowatt-hours per square meter) . Multiplying this figure times the solar area yields a possible range of annual energy savings from 9.6 million to 14 million Btu (2800–4100 kilowatt-hours):

Lowest savings = lowest savings per square foot × lowest solar area
= 40,000 Btu × 240 square feet
= 9,600,000 Btu
Highest savings = highest savings per square foot × highest solar area
= 50,000 Btu × 280 square feet
= 14,000,000 Btu

This house in Golden, Colorado uses flat plate water heating panels.

Flat-plate collectors are usually mounted flat on the roof, although they can be tilted by mounting them in a support rack. Some roof-mounted collectors are even designed to look like skylights, making them more aesthetically pleasing.

Most solar water heating systems have two main parts: the collector and a storage tank to hold the hot liquid. The storage tank can be just a modified water heater, but ideally it should be a larger, well-insulated tank. Systems that use fluids other than water usually heat the water by passing it through a coil of tubing in the storage tank, which is full of hot fluid. Many systems use a separate water heater as a backup to the solar water heating system.

Solar water heating systems can be either active or passive, but active systems are the most common.

Active solar hot water systems rely on pumps to move the liquid between the collector and the storage tank.

A simpler hot water system is the integrated collector system, often called a breadbox water heater. This design combines the collector with the storage tank, so the sun shines directly on the storage tank to heat it. Although cheaper, this system is usually less efficient. It's a passive system because it doesn't require a pump to shuttle water back and forth between the collector and the storage tank.

Another passive solar water heater is the "thermosyphon" system. Like the active system, the thermosyphon system uses a separate collector and storage tank, but the tank is mounted above the collector. Hot water rises just like a hot air balloon rises above the cooler air around it, so when the water heats up in the collector, it naturally tries to rise up to the tank. Also, when the water cools in the tank, it naturally tries to sink down to the collector. The combination of the hot water wanting to rise and the cool water wanting to sink causes the water to naturally flow between the collector and the tank—an effect called thermosyphoning.

Modern thermosyphon systems use a small box-shaped or cylindrical tank mounted just above the collector on the roof—the collector and tank are usually built as a single piece. The advantage of thermosyphon systems is their simplicity—because they have no pump or control system, there is less to go wrong, and they need less maintenance.

In addition to heating water for homes, solar water heating systems can also be used to heat swimming pools, extending the swimming season by several months. Pool systems are simple, because the pool's filter pump is used to pump the water through the collector, and the pool stores the hot water. Because the pool only needs to be heated a little, the collector can be very simple. Most pool collectors are made of black plastic or rubber and, like flat-plate collectors, have many tubes running through them to carry the water. To keep costs down, no glazing is used on the collectors.

The Solar Resource for Solar Water Heating

When most people think about solar radiation, they think of the sunlight coming directly from the sun, but sunlight actually reaches us from many directions. Some of it is scattered in the atmosphere and reaches us from all directions in the sky—in fact, the sky's blue color is scattered sunlight. Some sunlight is reflected off the ground, off other surroundings, and off clouds. This scattered and reflected sunlight is called "diffuse" solar radiation. Flat-plate solar collectors use both direct and diffuse solar radiation. The combination of the two is often called the "global solar radiation."

Although it is best to tilt the collectors at an angle equal to the latitude to catch the most sunlight, solar hot water collectors are usually mounted flat on the roof. This isn't a big concern, because in northern climates, roofs are generally pitched steeper, allowing the roof to withstand heavy snowfalls. In southern climates, where snow isn't a concern, roofs are flatter. But in general, roofs tend to be pitched at an angle less than the latitude. For the purpose of this discussion, we'll use the global solar radiation for a collector tilted 15 degrees lower than the latitude. For instance, if you live at 40 degrees latitude, we're assuming that your roof is pitched at 25 degrees.

The table on page 8 shows the average amount of global solar radiation received each day at an angle equal to latitude minus 15 degrees for cities throughout the United States. The box on page 8 shows how to use this table to figure out how much hot water a 40-square-foot (3.72-square-meter) collector can make on an average day.

For Los Angeles, the answer is 36 gallons (137 liters) a day, or about 55 percent of the hot water needs. In comparison, the same solar collector in Boston, Massachusetts, would produce about 29 gallons (110 liters) of hot water on an average day, or about 45 percent of the hot water needs. The table on page 9 shows this percentage for households throughout the country. Of course, you can produce more solar hot water by simply buying a larger solar collector.

Solar Energy for Nonresidential Buildings

Nonresidential buildings, such as commercial and industrial buildings, may use the same technologies for passive heating, daylighting, and water heating that are used in residential buildings. However, because of their size, heavy energy use, and special energy needs, nonresidential buildings can also use several solar technologies that are impractical for a home. In addition, solar energy systems are used in nonresidential buildings for ventilation air preheating, high-temperature water heating, and air conditioning.

Ventilation Air Preheating

Many large buildings, by their nature, require a large amount of ventilation air to maintain indoor air quality. In cold, northern climates, this air must often be heated from frigid temperatures up to room temperature. Because heating the air requires a heating system that uses large amounts of energy, any method of preheating the air saves money and energy. Another advantage of the preheating is that the heating system can be smaller and less expensive.

Solar ventilation preheating uses a thin, black metal panel mounted on a south-facing wall. This metal panel is not covered with glazing—instead, the panel has many small holes drilled into it, and the air is sucked, or transpired, through the holes. This device is called an "unglazed transpired collector." A space behind the perforated wall allows the air streams from each of the holes to mix together. The heated air is sucked out of the top of this space into the ventilation system.

Average Global Solar Radiation (for hot water panels installed at an angle equal to the latitude minus 15 degrees in U.S. cities)	
City	Daily Average Solar Radiation (kilowatt-hours per square meter per day)
Anchorage, Alaska	3.1
Phoenix, Arizona	6.4
Los Angeles, California	5.5
San Francisco, California	5.3
Colorado Springs, Colorado	5.5
Miami, Florida	5.1
Honolulu, Hawaii	5.5
Chicago, Illinois	4.4
New Orleans, Louisiana	4.9
Boston, Massachusetts	4.5
Minneapolis, Minnesota	4.6
Kansas City, Missouri	4.9
Helena, Montana	4.7
Albuquerque, New Mexico	6.3
New York City, New York	4.5
Bismarck, North Dakota	4.9
Cleveland, Ohio	4.2
Oklahoma City, Oklahoma	5.3
Nashville, Tennessee	4.8
San Antonio, Texas	5.3
Salt Lake City, Utah	5.2
Richmond, Virginia	4.7
Seattle, Washington	3.8

A transpired solar collector (the dark material running along the top of the building) helps heat this helicopter maintenance hangar.

Solar Resource for Unglazed Transpired Collectors

Unglazed transpired collectors are simple, inexpensive, and highly efficient—typically 60 to 70 percent. Because of all these advantages, the length of the heating season is the main issue when considering an unglazed transpired collector. Because unglazed transpired collectors are used only when the outside air is cool, they work best in cold, sunny climates.

The solar resource for unglazed transpired collectors is similar to that for residential hot water systems (see page 5), but there are several differences.

A typical size for a flat-plate solar collector is 40 square feet (4 feet by 10 feet), which is equal to 3.72 square meters. For a house in Los Angeles on an average day, a collector that size would receive about 20.5 kilowatt-hours of solar energy:

3.72 square meters × 5.5 kilowatts-hours per square meter per day (on average)
= 20.5 kilowatt-hours per day

Because flat-plate solar collectors are only about 35 percent efficient, the collector would produce 7.2 kilowatt-hours of heat on an average day:

20.5 kilowatt-hours per day × 0.35 = 7.2 kilowatt-hours per day

This is the equivalent of 24,500 Btu. To find out what that means, it's important to know that the average water heater starts with cold water at about 50EF (10EC) and heats it to 130EF (54EC). To do that for 1 gallon (3.8 liters) of water takes about 667 Btu, which is equal to 0.2 kilowatt-hours of heat. So in Los Angeles, a 40-square-foot solar collector (which collects 7.2 kilowatt-hours per day) could produce roughly 36 gallons (137 liters) of hot water each day:

7.2 kilowatt-hours per day ÷ 0.2 kilowatt-hours per gallon = 36 gallons per day

Because the average household uses about 65 gallons (247 liters) of hot water each day, one 40-square-foot solar collector in Los Angeles could provide about 55 percent of the hot water needs:

36 gallons ÷ 65 gallons = 0.55 = 55 percent

Result of Hot Water Fraction Calculation	
City	Solar fraction, percentage
Anchorage, Alaska	31
Phoenix, Arizona	64
Los Angeles, California	55
San Francisco, California	53
Colorado Springs, Colorado	55
Miami, Florida	51
Honolulu, Hawaii	55
Chicago, Illinois	44
New Orleans, Louisiana	49
Boston, Massachusetts	45
Minneapolis, Minnesota	46
Kansas City, Missouri	49
Helena, Montana	47
Albuquerque, New Mexico	63
New York City, New York	45
Bismarck, North Dakota	49
Cleveland, Ohio	42
Oklahoma City, Oklahoma	53
Nashville, Tennessee	48
San Antonio, Texas	53
Salt Lake City, Utah	52
Richmond, Virginia	47
Seattle, Washington	38

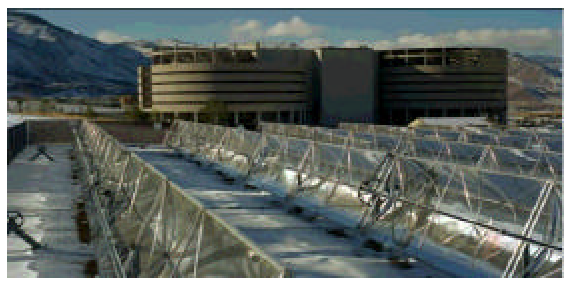
Because unglazed transpired collectors are mounted on walls, they are tilted at an angle much greater than the latitude. However, because they are needed most in the winter when the sun is low, their high angle of tilt actually works to their advantage. During the crucial cool-air months of December and January, a wall-mounted collector will usually receive more solar energy than a collector tilted at an angle equal to latitude.

Water Heating

Nonresidential buildings can use "evacuated-tube" collectors to meet their high energy needs. These collectors are shallow boxes that hold many side-by-side glass tubes, which carry the fluid to be heated. Reflectors under the tubes help bounce the sunlight onto them. But the special feature of these collectors is a glass outer tube that surrounds the tube carrying the fluid. The space between the two tubes is in a vacuum; in other words, it is "evacuated." This vacuum is an extremely good insulator—thermos bottles use the same principle to keep your coffee hot—so the tube carrying the water loses very little heat. This allows the collector to operate at high temperatures with high efficiency.

This Fort Huachuca, Arizona office building is heated by a evacuated-tube collector system.

Nonresidential buildings can also use "parabolic-trough" collectors. Parabolic troughs are long rectangular mirrors formed in a U-shape, like watering troughs. The mirrors are tilted toward the sun to focus the sunlight on a tube, running down the center of the trough, which carries the fluid to be heated. A tracking device keeps the mirrors pointed toward the sun. The shape of the mirrors—technically, a "parabola"—is perfect for focusing the sunlight on the tube. Because of this concentrated sunlight, parabolic troughs also operate at high temperatures with high efficiency.



The Jefferson County, Colorado jail solar thermal system is a parabolic-trough design.

Large buildings can use many of these evacuated-tube or parabolic-trough collectors hooked together to produce a large amount of hot fluid. This hot fluid can be used to heat water for industrial uses or for showers, kitchens, and laundry facilities. It may also be used to heat air for industrial processes, or for air conditioning, as explained below.

Refrigeration and Air Conditioning

The heat from solar collectors can be used to run refrigerators or to cool a building. It may seem strange to use heat for cooling, but if you think of heat as just another form of energy, it's not so different from using electricity to run an air conditioner or refrigerator.

Electric air conditioners work by using the hot air from the building to boil a refrigerant fluid, such as freon. The refrigerant fluid is kept at a low pressure so that it boils at a very low temperature. Boiling the fluid uses a lot of energy, so the fluid draws the heat out of the air and makes the air cool.

Cooling the air is the easy part—the hard part is turning the refrigerant vapor back into liquid so that it can be used again. And of course that requires energy—electricity in this case. Most of the electricity is used to run a compressor that raises the pressure of the freon vapor. The vapor is then passed through a condenser. At this higher pressure, cool water is sufficient to condense the vapor back into liquid so it can be boiled again.

Solar coolers use a similar approach, but the compressor and condenser are replaced by an absorbent liquid and a pump. Rather than first compressing the refrigerant vapor and then turning it into liquid, the absorbent liquid absorbs the refrigerant vapor, in effect turning it into a liquid. Then this mixture of absorbent and refrigerant liquid is pumped up to a higher pressure.

This "absorption cooling" scheme seems as if you're getting something for nothing—instead of the compressor, which uses a lot of electricity, you're using a pump, which uses only a small amount of electricity. And the absorbent liquid doesn't use any energy at all. But of course, there's a price to be paid for taking this shortcut, because you're left with a mixture of refrigerant and absorbent liquid, and you need to separate the two to get back to where you started.

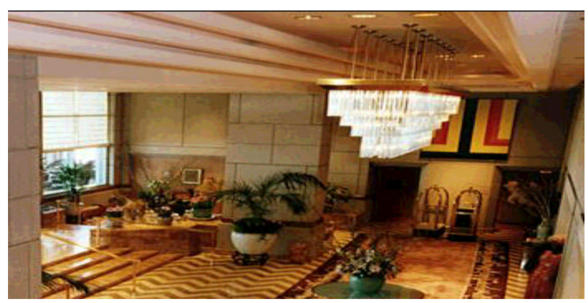
Waste-heat powers the ammonia absorption refrigeration unit at this Diamond Shamrock refinery.

And that's the job for solar energy. Solar energy is used to heat the mixture, driving off the refrigerant vapor from the absorbent liquid. Then the refrigerant vapor is condensed using cool water (just like in the electric air conditioner) and it's ready to be reused, completing the cycle.

Seem confusing? It is. This is a complex system with many steps. But here's the important point: the step that uses the most energy is removing the vapor from the absorbent liquid, and solar energy can provide the heat needed for that step.

A simpler approach to solar cooling is to use the solar heat as part of an evaporative cooler, often called a swamp cooler. These coolers work by evaporating water into the incoming air—the water absorbs heat as it evaporates, cooling the air.

Evaporative coolers work well in dry climates such as the Southwest, but their use can be extended to humid climates by dehumidifying the air before it passes into the cooler. To dry the air, it is passed over a "desiccant"—a material that absorbs moisture. The most common desiccant is pea-sized white beads of silica gel.



The Park Hyatt Hotel in Washington, DC uses two rooftop desiccant units to handle the air requirements for the lobby and hallways.

Unfortunately, silica gel can only absorb so much water. Once it's saturated, it needs to have the moisture removed by heating; that's where solar energy comes in. Solar energy can be used to heat the silica gel, driving off the moisture. Then the silica gel can be put back into the cooling system to absorb more water. This saves the energy that would normally be needed for an electric or gas heater to warm the beads.

Solar Resource for Nonresidential Hot Water and Cooling Systems

Nonresidential buildings benefit from solar hot water and cooling systems because the solar resource is available during normal business hours, when many nonresidential buildings have their highest energy needs. This is especially true for solar cooling, because more cooling is needed when the sun is shining. This makes solar cooling an ideal match between the resource and its application.

The available solar resource is different for evacuated-tube collectors versus parabolic-trough collectors. Evacuated-tube collectors use both direct and diffuse sunlight—a resource we introduced earlier as global solar radiation (see page 7). Parabolic troughs are different because they focus and concentrate the sunlight. This actually reduces the solar resource that they can draw from, because they collect only the direct sunlight and not the diffuse sunlight. However, their high efficiency makes up for that loss.

The high efficiencies at high temperature make evacuated-tube and parabolic-trough collectors the technology of choice for nonresidential buildings. At the temperatures used in homes, these collectors operate at about the same efficiencies as flat-plate collectors, and they cost more. But nonresidential systems usually operate at high temperatures; this is especially true for solar cooling systems. At these high temperatures, the efficiency of flat-plate collectors drops rapidly, but the evacuated-tube and parabolic-trough collectors maintain their high efficiencies.

The choice between flat-plate and parabolic-trough collectors is based on the specific requirements for the system and on the solar resource available. In general, flat-plate collectors have an advantage in humid climates, where the haziness of the air scatters more of the sunlight. This reduces the amount of direct sunlight available for the parabolic trough.

Photovoltaic Energy

All of the technologies discussed so far collect solar energy in the form of heat and use it for either heating or cooling. But in addition to these technologies, we have an option that converts sunlight directly into electricity—photovoltaic (PV) cells. PV cells are the solar cells that are often used to power calculators and watches.

PV cells are made of semiconducting materials similar to those used in computer chips. When sunlight is absorbed by these materials, the solar energy knocks electrons loose from their atoms, allowing the electrons to flow through the material to produce electricity. This process of converting light (photons) to electricity (voltage) is called the "photovoltaic effect."

Although solar cells for calculators are very small, a typical PV cell measures about 4 inches (10 centimeters) square. These cells can produce about 1 watt of power—more than enough to keep your watch ticking, but not enough to run your radio. When more power is needed, roughly 40 PV cells can be connected together to form a "module." A typical PV module is powerful enough to light a small light bulb. For larger power needs, about 10 of these modules are mounted in PV "arrays" that can measure up to several meters on a side.

These "flat-plate" PV arrays can be mounted at a fixed angle facing south, or they can be mounted on a tracking device that follows the sun, allowing them to capture the most sunlight over the course of a day. Ten to twenty PV arrays can provide enough power for a household; for large electric utility or industrial applications, hundreds of arrays can be interconnected to form a single, large PV system.

These single-axis tracking flat-plate photovoltaic arrays provide electricity to California residents.

Some PV cells are designed to operate with concentrated sunlight. These cells are built into "concentrating collectors" that use a lens to focus the sunlight onto the cells. This approach has both advantages and disadvantages compared with flat-plate PV arrays. The main idea is to use very little of the expensive semiconducting PV material while collecting as much sunlight as possible. But because the lenses must be pointed at the sun, the use of concentrating collectors is limited to the sunniest parts of the country. Some concentrating collectors are designed to be mounted on simple tracking devices, but most require sophisticated tracking devices, which further limit their use to electric utilities, industries, and large buildings.

This concentrating PV system operates reliably for the Central and Southwest Services utility in Fort Davis, Texas.

PV Cell Efficiency

The performance of a PV cell is measured in terms of its efficiency at turning sunlight into electricity. If a PV cell could turn all the sunlight shining on it into electricity—operating at 100 percent efficiency—a PV array only about 45 square feet (5 feet by 9 feet, or 4.2 square meters) in size could power a home in Phoenix, Arizona. But many things happen to the sunlight as it hits the PV array. Some of the light is reflected, some passes right through the cell, some is absorbed by other materials (such as the glazing), and much of it merely heats the PV cell without generating electricity. Only sunlight of certain energies will work efficiently to create electricity.

Large-scale photovoltaics systems like this one provide grid support for electric utilities.

The efficiency of PV cells is limited by all the sunlight that gets lost without creating electricity. A typical commercial PV cell, for instance, has an efficiency of 15 percent—about one-sixth of the sunlight striking the cell generates electricity—although the best cells built for space applications have efficiencies approaching 30 percent. Low efficiencies mean that larger arrays are needed, which translates into higher costs. Improving PV cell efficiencies while holding down the cost per cell is an important goal of the PV industry and researchers at the U.S. Department of Energy, who have made significant progress. The first PV cells, built in the 1950s, had efficiencies of less than 4 percent.

PV Applications

The main advantages of PV cells are their stand-alone capability, portability, low environmental impact, and high reliability. These benefits make PV cells ideal for small-scale applications like watches and calculators, but they are also helping PV systems find their way into larger applications.

Currently, the largest market for PV systems is for medium-scale applications (from 5 to 5000 watts). These applications take advantage of the systems' stand-alone capability, and most are located in remote areas not served by a utility power grid. Such medium-scale applications include water pumping, highway lighting, navigational buoys, lighthouses, microwave repeater stations, and weather stations—basically, any remotely located piece of electrical equipment that needs to operate reliably with minimal maintenance. Somewhat larger PV systems supply most or all of the power needs for remote homes and cabins in tens of thousands of locations worldwide.

This portable PV unit pumps up to 1.75 gallons per minute from a 60-foot well to keep a stock tank filled.

Large-scale uses of PV systems (from 500 to 2000 kilowatts) are still in their infancy. Several large systems—capable of powering hundreds of homes—are now connected to utility electric grids throughout the United States. Utilities are investigating the use of such large PV systems in areas where the added power needed for new industries and homes is overloading the power lines. Rather than replace power lines and transformers, a PV system can be located at the *end* of the power lines, close to the homes, to provide the extra power needed. In many areas, the need for power is greatest at midday, when the PV systems are producing the most power.

A variation on this theme is mounting the PV arrays on the rooftop of the homes, but still connecting them to the power grid. Rooftop-mounted PV arrays have the advantage of not using any additional land. As the ultimate refinement of this idea, the U.S. Department of Energy and several PV manufacturers are investigating PV arrays that would actually be a structural part of the roof. This will save money by producing power without using land, while serving as a durable and long-lasting roof. Imagine a house that generates its own power!

The Solar Resource for PV Systems

The solar resource for generating power from PV systems is ample. For instance, covering about 9 percent of the area of Nevada (a plot of land 100 miles on a side) with today's PV arrays would provide enough electric power for the entire country.

The amount of power generated by a flat-plate PV array at a particular site depends on how much of the sun's energy reaches it from all directions—the global solar radiation concept again. PV arrays are usually tilted at an angle equal to the site's latitude, which allows the array to capture the most sunlight over the course of a year. So the important resource data for PV arrays is the global solar radiation at an angle equal to the latitude.

The situation is different for concentrating PV collectors. These are similar to solar thermal technologies like parabolic troughs, because they use only the direct-beam sunlight rather than the global solar radiation. However, because they are mounted on tracking devices to follow the sun, they gather almost as much energy as a flat-plate PV array. The higher efficiency of concentrating PV collectors means that they actually produce more electricity per square meter than does a flat-plate PV array.

Here is a simplified example of how to use solar radiation data for sizing a PV system using flat-plate PV arrays. Let's say we want a system to power an outdoor light. We'll want to use the minimum amount of energy possible to keep the PV system small, so we'll use a high-efficiency compact fluorescent light. An 18-watt compact fluorescent light gives off as much light as a normal 70-watt bulb.

Assuming a worst-case long winter night, let's guess that the bulb needs to run for 16 hours (this should be fine for every state except Alaska). To keep the bulb running all night, we need:

18 watts × 16 hours = 288 watt-hours of energy

Now we need to size a PV system to provide that much energy during a worst-case winter month, when the days are short and the sun is low. The size will depend on where the system will be located. The table on this page shows the annual daily average of the global solar radiation for several cities, and also the daily average for the worst-case month (usually December).

For Colorado Springs, Colorado, during the worst-case month, the daily global radiation is 4400 watt-hours per square meter. We can figure out the size of the array needed by taking the energy needed to run the bulb all night and dividing it by the daily global radiation:

288 watt-hours ÷ 4400 watt-hours per square meter = 0.0654 square meters

This is equal to 654 square centimeters (about 100 square inches).

Now we need to factor in the efficiency of converting the sunlight to electricity. A typical PV array may be about 12 percent efficient, but for this application, the PV power has to be used to charge a battery during the day, so the battery can run the light at night. Using an overall efficiency of 10 percent will allow for energy losses in the battery and the charging system. That means we need a PV array that's 10 times larger:

654 square centimeters ÷ 10 percent (0.10) = 6540 square centimeters (1000 square inches)

Average Solar Radiation (kilowatt-hours per square meter per day)		
City	**Average Solar Radiation per Day throughout the year**	**Average Solar Radiation per Day in December**
Anchorage, Alaska	3.0	0.6
Phoenix, Arizona	6.5	4.9
Los Angeles, California	5.6	4.2
San Francisco, California	5.4	3.4
Colorado Springs, Colorado	5.6	4.4
Miami, Florida	5.2	4.5
Honolulu, Hawaii	5.7	4.8
Chicago, Illinois	4.4	2.4
New Orleans, Louisiana	5.0	3.7
Boston, Massachusetts	4.6	2.9
Minneapolis, Minnesota	4.6	2.7
Kansas City, Missouri	4.9	3.3
Helena, Montana	4.7	2.6
Albuquerque, New Mexico	6.4	5.0
New York City, New York	4.6	2.8
Bismarck, North Dakota	4.9	3.0
Cleveland, Ohio	4.1	1.9
Oklahoma City, Oklahoma	5.4	4.1
Nashville, Tennessee	4.9	3.1
San Antonio, Texas	5.4	4.1
Salt Lake City, Utah	5.3	2.9
Richmond, Virginia	4.8	3.3
Seattle, Washington	3.7	1.4

Average global solar radiation for PV panels installed at an angle equal to the latitude in cities throughout the United States.

The box on page 13 shows you how to use the global solar radiation table above to figure out the necessary size of a PV array to light an outdoor security light. The calculations take a simple approach to give you some idea of what the resource numbers really mean. Using this simple design approach, the sizes of the PV arrays needed for each city are shown he table on page 15.

Solar Thermal Electric Power

In today's nuclear and fossil-powered plants, electricity is generated by first boiling water to make steam, then using the steam to rotate a large turbine. The turbine is just rows and rows of blades mounted on a large shaft. The pressure of the steam flowing through the turbine pushes against the blades and causes the shaft to turn, much like spinning a pinwheel by blowing on it. The turbine shaft is attached to a generator (the pairs are often called turbine generators), and the spinning generator produces electricity.

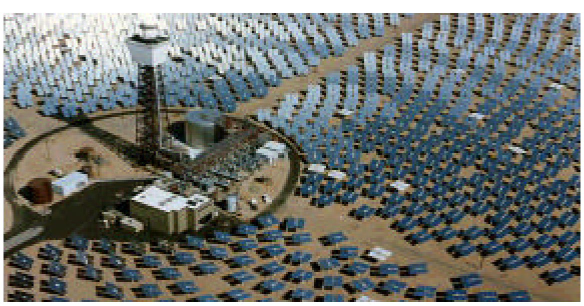
These power plants use coal, natural gas, nuclear energy, or oil as the source of heat, but a new generation of power plants is using the heat of the sun. There are now three main types of solar thermal electric power plants: central receivers, parabolic troughs, and dish/engine systems.

Central Receiver Plants

Central receiver plants use a large field of mirrors to concentrate sunlight onto the top of a tower. The mirrors are mounted on sophisticated computer-controlled mounts that track the sun. The tower is located in the *center* of the field of mirrors, and it *receives* the sun's heat, so it's called the "central receiver." By virture of their design, central receiver plants are large power plants that provide power to electric power grids.

Result of PV Panel Calculation	
City	PV Panel Area (square centimeters)
Anchorage, Alaska	48,000
Phoenix, Arizona	5,878
Los Angeles, California	6,857
San Francisco, California	8,471
Colorado Springs, Colorado	6,545
Miami, Florida	6,400
Honolulu, Hawaii	6,000
Chicago, Illinois	12,000
New Orleans, Louisiana	7,784
Boston, Massachusetts	9,931
Minneapolis, Minnesota	10,667
Kansas City, Missouri	8,727
Helena, Montana	11,077
Albuquerque, New Mexico	5,760
New York City, New York	10,286
Bismarck, North Dakota	9,600
Cleveland, Ohio	15,158
Oklahoma City, Oklahoma	7,024
Nashville, Tennessee	9,290
San Antonio, Texas	7,024
Salt Lake City, Utah	9,931
Richmond, Virginia	8,727
Seattle, Washington	20,571

The only central receiver plant in the United States is located in Barstow, California. It was built as an experimental facility and was originally called "Solar One." The plant's centerpiece was a 91-meter (300-foot) tower, surrounded by 1800 mirrors. Solar One produced power by pumping water up the tower and boiling it in the central receiver, then sending steam back down the tower to a turbine generator. The plant was large enough to power about 10,000 houses, and it generated electricity for 8 years before it was mothballed in 1988.



Solar One is the only central receiver plant in the United States.

That was the end of Solar One, but it was reborn in 1996 with the name "Solar Two," using a new design based on molten (liquefied) salt. In this design, "cool" molten salt—at 290EC (550EF), roughly the melting point of lead—is pumped up the tower to collect the heat. Once heated, the hot molten salt—at 565EC (1050EF), nearly the melting point of aluminum—flows back down the tower. The hot salt provides heat to a boiler, which boils water to steam. The steam is sent to a turbine generator to produce electricity, then condensed and reused.

Molten salt absorbs the sun's heat better than water does, so Solar Two is more efficient at turning sunlight into electricity. Molten salt also has a high heat capacity; it can hold a great deal of heat for a long time. Just as fireplace bricks stay warm long after the fire has died, so will the molten salt stay hot even when the sun isn't shining. This ability to store the sun's heat will allow the plant to *collect* the sun's energy when the sun is shining, but to continue *producing* electricity when clouds block the sun, or even several hours after sunset.

Parabolic Troughs

Parabolic troughs, described earlier as a way to heat water, are another solar thermal technology. Parabolic troughs are long rectangular mirrors curved into U-shapes, like watering troughs. The mirrors are tilted toward the sun to focus sunlight on a tube that runs down the center of the trough.

For electricity production, oil flows through the tube instead of water. Oil absorbs the sun's heat better than water does, raising the efficiency of the collector. In addition, oil can be heated to higher temperatures than water, which also increases the efficiency. After the oil absorbs the sun's heat, the heat of the hot oil is used to boil water in a boiler. Again, the steam from the boiler drives a turbine generator to produce electricity.

Parabolic troughs are the leading solar thermal electric technology. Several parabolic-trough projects in California's Mojave Desert are supplying more than 350 megawatts of generating capacity—equivalent to a small coal plant—to Southern California Edison's power grid.

Dish/Engine Systems

Dish/engine systems use a mirrored parabolic dish (similar to a satellite dish) to concentrate the sun's heat onto a metal absorber. The heat is conducted through the metal to a heat engine, where the heat causes a gas to expand and push against a piston. The movement of the piston is then used to run a small electric generator to produce electricity. Because the dish must be aimed directly at the sun, the dish is mounted on a sophisticated tracking device.

Although these are called dishes, often several separate mirrors are used rather than one large dish-shaped mirror. This "faceted" design saves money, although it does cause some loss in efficiency. However, new methods of making large mirrors are now cutting their costs enough that single dish-shaped mirrors may become the preferred choice.

Dish/engine systems can be hooked together in an array and used to provide power to an electric power grid, but they are more commonly used like diesel generators—as individual sources of power in remote locations. Dish/engine systems are often used in developing countries to replace or supplement a diesel generator. Depending on the size of the dish, the systems can generate up to 25 kilowatts of power—enough for several households or a small village.

This dish concentrator powers a Stirling engine.

The Solar Resource for Solar Thermal Electric Systems

Solar thermal electric systems all use tracking systems to point their mirrors toward the sun. For this reason, they depend on the solar radiation that is coming straight to the mirrors, direct from the sun. This is called the "direct solar radiation."

Central receivers and dish/engine systems point their mirrors straight at the sun, so they capture the greatest amount of direct solar radiation. Because the light is all focused on a point, these systems also highly concentrate the sunlight, allowing them to operate at high temperatures and high efficiencies.

Parabolic troughs are usually mounted flat on the ground, with the tubes horizontal. This causes the sunlight to come into the mirrors at an angle, so they capture slightly less energy—compare the numbers in the table below. Parabolic troughs concentrate the sunlight less than central receivers and dish/Stirling systems, because troughs concentrate the light along the line of the central tube rather than on a single point. For this reason, they operate at lower temperatures and lower efficiencies.

Average Direct Solar Radiation per Day for Solar Thermal Electric Systems in U.S. Cities

Average direct solar radiation (kilowatt-hours per square meter per day)

City	Dish/Engine and Central Receiver Systems	Parabolic Troughs
Anchorage, Alaska	2.3	1.8
Phoenix, Arizona	6.8	6.0
Los Angeles, California	4.8	4.2
San Francisco, California	5.0	4.4
Colorado Springs, Colorado	5.6	4.8
Miami, Florida	4.0	3.6
Honolulu, Hawaii	5.2	3.8
Chicago, Illinois	3.4	2.9
New Orleans, Louisiana	5.0	3.6
Boston, Massachusetts	3.7	3.1
Minneapolis, Minnesota	4.0	3.3
Kansas City, Missouri	4.4	3.8
Helena, Montana	4.5	3.8
Albuquerque, New Mexico	6.7	5.9
New York City, New York	3.5	2.9
Bismarck, North Dakota	4.5	3.7
Cleveland, Ohio	3.0	2.7
Oklahoma City, Oklahoma	5.0	4.4
Nashville, Tennessee	3.9	3.4
San Antonio, Texas	4.5	4.1
Salt Lake City, Utah	5.1	4.5
Richmond, Virginia	3.9	3.4
Seattle, Washington	2.9	2.5

Number of Homes That Could Be Powered by One 11-Meter Dish/Engine System	
City	**Number of Homes Powered**
Anchorage, Alaska	1.9
Phoenix, Arizona	5.7
Los Angeles, California	4.0
San Francisco, California	4.2
Colorado Springs, Colorado	4.7
Miami, Florida	3.3
Honolulu, Hawaii	4.3
Chicago, Illinois	2.8
New Orleans, Louisiana	3.3
Boston, Massachusetts	3.1
Minneapolis, Minnesota	3.3
Kansas City, Missouri	3.7
Helena, Montana	3.8
Albuquerque, New Mexico	5.6
New York City, New York	2.9
Bismarck, North Dakota	3.8
Cleveland, Ohio	2.5
Oklahoma City, Oklahoma	4.2
Nashville, Tennessee	3.3
San Antonio, Texas	3.8
Salt Lake City, Utah	4.3
Richmond, Virginia	3.3
Seattle, Washington	2.4

In the United States, solar thermal electric power is considered most feasible in the desert Southwest. The clear skies and the strong sunlight there combine to offer a large solar energy resource. The table on page 16 clearly shows this advantage. Phoenix, Arizona, receives more than twice as much direct solar radiation than Boston, Massachusetts.

These numbers take on more meaning if we imagine building dish/engine systems in different parts of the country. The box below shows how to apply these numbers to a dish/engine system in an ideal location in southeast Nevada. An 11-meter dish there could supply power to seven homes. In comparison, a dish of the same size located in Kansas City, Missouri, could produce enough electricity to power about three homes. The table at left shows the result of performing this calculation for all of the cities listed in the table.

Here's how to apply the direct solar radiation to a solar thermal system—in this case, a dish/engine system. Let's use a dish 11 meters (37 feet) in diameter, for which the total area of the mirror is about 100 square meters. The part of the country that receives the most direct solar radiation—the southern border between Utah and Nevada—receives about 8.25 kilowatt-hours per square meter each day. A mirror at that location could gather about 825 kilowatt-hours of energy each day:

(8.25 kilowatt-hours per square meter per day) × 100 square meters = 825 kilowatt-hours per day

We now need to take into account how well the system converts the energy into electricity. The best systems can convert this energy to electricity with an efficiency of about 29 percent, but today's designs have sacrificed some efficiency to greatly reduce costs. Today's systems operate at efficiencies of 19–25 percent. Using the higher number, we need to multiply the energy gathered by the mirror times 0.25:

(825 kilowatt-hours gathered per day) × 0.25 = 206 kilowatt-hours produced per day

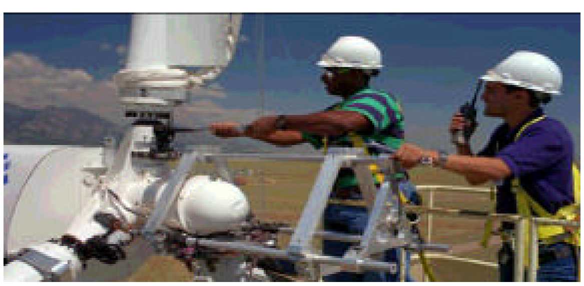
Because a typical household uses about 30 kilowatt-hours per day, this is enough electricity to power about seven homes.

Wind Power

For hundreds of years, people have been using windmills to harness the energy of the wind. Windmills are familiar symbols of old Holland and were once essential for pumping water on farms throughout the United States. Windmills use the wind to turn a shaft, and usually that shaft either turns a millstone to grind grain or drives a pump to pump water. The basic idea of capturing wind energy finds its high-technology equivalent in today's "wind turbines." Rather than grinding grain or pumping water, modern wind turbines use wind energy to generate electricity.

This modern-day wind turbine is undergoing testing at the Whitewater wind farm in California.

Wind turbines use propeller-like blades to catch the wind energy. Usually, two or three blades are mounted on a shaft to form a "rotor." Each blade acts like an airplane wing—when the wind blows by it, a pocket of low-pressure air forms on the downwind side of the blade. This low-pressure air pocket pulls the blade toward it (an effect known as "lift"), causing the rotor to turn. The lift is actually a much stronger force than the force of the wind pushing against the front side of the blade, which is known as "drag."



Researchers at the National Wind Technology Center are measuring the effects of wind pressure on this wind turbine rotor.

The combination of lift and drag forces cause the rotor to spin like a propeller in the wind, and the turning shaft spins a generator to make electricity. Like windmills, wind turbines are mounted on a tower to capture the most energy, because the wind is faster and less turbulent at 100 feet (30 meters) or more above the ground.

Wind Applications

Wind turbines can be used for stand-alone applications, or they can be connected to a utility power grid. Stand-alone wind turbines are used for some of the same applications as PV systems—water pumping and communications. In fact, wind turbines are often combined with PV systems for these applications. Homeowners and farmers in windy areas also use wind turbines as a way to cut their electric bills.

When supplying power to electric utilities, it's usually more efficient to build many wind turbines in the same area to form a large array, often called a "wind plant." Wind plants are often more cost-effective than lone wind turbines because the electric power lines from all of the wind turbines in a wind plant can be hooked together and attached to the local utility power grid. This setup is very reliable—at any time, several wind turbines at a wind plant may be shut down for maintenance, but most of the turbines are running.

The Wind Resource

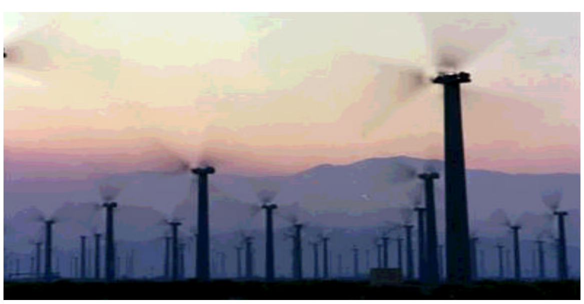
Wind power has already proven itself in California, where harnessing the wind now produces enough power for about 300,000 homes. Most of the wind power comes from wind plants in mountain passes at Altamont, east of San Francisco; at Tehachapi, northeast of Los Angeles; and at San Gorgonio Pass, northwest of Palm Springs. But these wind plants represent only a small portion of our country's potential for wind power.

To understand the wind resource, it's important to understand what causes wind. Winds are driven partly by the Earth's rotation, but mainly by temperature differences caused by sunshine. For this reason, wind is considered an indirect form of solar energy. But unlike solar resources, wind resources vary widely with the local geography. Mountain passes are often extremely windy because the wind pushing against the mountain gets squeezed through the pass. On the other hand, a site downwind of a hill may get very little wind at all.

The wind resource map above shows these differences. The map divides the average wind speeds into different power classes: Class 7 winds are tremendously strong, and Class 2 winds are mild. Because wind turbines installed during the 1980s needed a high average wind speed to generate power economically, most of the U.S. wind turbines have been built in Class 5 areas in mountain passes.

New turbine designs are now taking advantage of less windy areas by using better blades, more efficient electronics, and other such improvements. Some new turbines also operate at variable speeds; the earlier wind turbines ran only at one speed. Variable-speed operation allows wind turbines to operate efficiently over a broad range of wind speeds and, in turn, to capture more wind energy.

Together, these advances are allowing this new generation of wind turbines to generate inexpensive power from the more moderate Class 4 winds, such as those that blow on the great plains of the Midwest. As shown in the wind resource map, this area has a large wind resource that is fairly constant throughout hundreds of square miles. Because of these advances, wind turbines are being built throughout the country—from Texas to Minnesota and from Washington to Vermont.



The Sea-West wind farm in Palm Springs, California.

Today's turbines are economical for Class 4 areas, and a wind plant using these turbines should be able to generate about 11.6 million kilowatt-hours per square kilometer of land per year, or about 4.5 million kilowatt-hours per square mile per year. One household uses about 11,000 kilowatt-hours per year, so one square mile of land could generate enough power for about 410 homes.

To see how this adds up, a U.S. Department of Energy study looked at the amount of land available for wind development in the continental United States and compared it to the available wind resource. The study excluded urban areas, much of the forest and agricultural land, and land that is environmentally sensitive. Even with these restrictions, the study found that the new wind turbines could generate more than one and a half times (150 percent) as much electricity as is now being used in the entire country. As shown in the map, most of the power could be generated in the plains of the Midwest. The northeastern and the western regions could also generate a meaningful fraction of their electricity from the wind.

Future design improvements should make it cost-effective to generate power from Class 3 winds. Areas that are now useless for wind power should be able to generate about 9 million kilowatt-hours per square kilometer of land per year, or about 3.5 million kilowatt-hours per square mile per year—enough power for about 320 homes per square mile. Using these areas could boost the generation of electricity to more than four times the electricity that is now being used throughout the country.

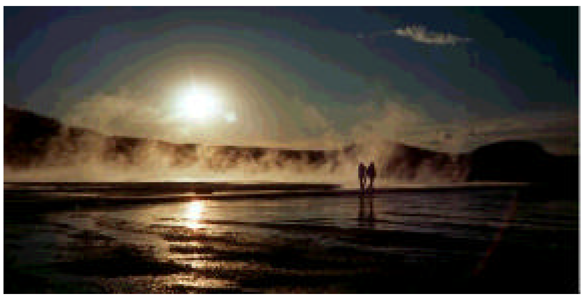
Geothermal Direct Use

Geothermal energy is caused by molten rock (magma) welling up miles below the Earth's surface and heating a section of the Earth's crust. Under the right conditions, the heat rising from the magma can warm underground pools of water, creating underground reservoirs of hot water, known as "geothermal reservoirs." Sometimes, the water can even boil to steam. These reservoirs are typically located about 2 miles (3.3 kilometers) below the Earth's surface.

If there is an open path through the rock to the surface, the hot underground water may seep out to form hot springs. It may also boil to form geysers. Although geysers are rare, hot springs are found throughout the United States, mostly in the West.

"Direct" use of geothermal energy means that we use the hot water to heat something else, as opposed to using it to generate electricity. Geothermal reservoirs at temperatures greater than 115EC (240EF) can be used for power generation; direct-use applications usually use lower temperature reservoirs.

Geothermal direct use dates back thousands of years to when early civilizations used hot springs for bathing, cooking food, and loosening feathers and skin from game. To this day, many hot springs are still used as spas, but more sophisticated uses of geothermal hot water have also been developed.



The hot spring pools in Yellowstone National Park, Wyoming.

For modern uses of geothermal energy, a well is drilled into the geothermal reservoir to provide a steady stream of hot water.

Geothermal hot water can be used to heat buildings. Individual buildings can be heated with small wells, but usually it is more economical to use one large well to heat many buildings by piping the hot water from building to building. This technique, known as "district heating," was first used in Boise, Idaho, in 1892. Today, the United States has 17 operating geothermal district heating systems.

Geothermal hot water can be used for many other applications that require heat. It is currently used for heating greenhouses, pasteurizing milk, de-icing roads, heating water in fish farms, dehydrating foods, growing mushrooms, and heating leaching solutions at a gold mine. In addition, geothermal heat has been used for cooking, distilling, and grain drying in an alcohol fuel plant. Geothermal heat is even being used as the energy source for a heat-driven air-conditioning system, cooling five buildings at the Oregon Institute of Technology.

These geothermal direct-use applications save energy and increase U.S. energy independence. A 1990 survey found that these applications were using nearly 6 billion Btu (6 billion megajoules) of geothermal energy each year—the energy equivalent of nearly 1 million barrels (159 million liters) of oil.

Geothermal Heat Pumps

Geothermal heat pumps are a relatively new application of geothermal energy that has grown rapidly in recent years. Geothermal heat pumps save energy while heating and cooling homes and businesses.

These heat exchangers and circulation pumps are part of the geothermal district heating system in Klamath Falls, Oregon.

at pumps work much like your refrigerator. Using electricity, a refrigerator keeps a cool space (inside the refrigerator) cool by moving heat from the cool space to a warmer space (your kitchen). During the summer, a heat pump does the same thing, keeping your house cool by moving heat out of your house to the outdoors. During the winter, it provides heat by working in reverse, drawing heat from the cold outdoors (yes, even cold air has heat in it—it can always get colder) into your relatively warm house.

Many people are familiar with air-source heat pumps, which move heat between the air inside the home and the air outside the home. These heat pumps tend to operate inefficiently because of the extremes in outside air temperatures: It's difficult to pump heat into the outside air during a heat wave, and it's difficult to draw heat out of Arctic air.

Geothermal heat pumps avoid these problems by using the relatively constant-temperature earth as the heat source during the winter and heat sink during the summer. Using pipes buried underground, the geothermal heat pumps move heat between your home and the soil, which maintains a steady cooltemperature of roughly 11EC (52EF). It's easier to pump heat into cool soil than into hot air, and it's also easier to draw heat from cool earth than from frigid air, so geothermal heat pumps operate much more efficiently than air-source heat pumps.

Because of their high efficiency, geothermal heat pumps can cut annual heating costs by as much as 50 percent and cooling costs by as much as 25 percent.

The Geothermal Resource for Direct Use

Geothermal resources for direct heating are different from most other renewable energy resources, especially solar, because geothermal resources are concentrated in relatively small pockets underground.

A reservoir may cover several square miles, but this is small compared to the vast, uninterrupted solar energy resource in the Southwest or the wind resources in the Midwest. Although geothermal energy is an immense resource, it's more localized, so it requires more effort to locate and develop.

For this reason, there is no simple map or table to turn to for geothermal hot water resources. The map on page 21 shows the most likely locations in the United States, based on the known locations of hot springs and on other geologic data. But this is a crude indicator. Some hot springs are unsuitable for development; on the other hand, some geothermal reservoirs do not create hot springs, so there is no obvious sign on the surface that the resource is beneath you. To find these resources requires a knowledge of geology to find likely locations, followed by detailed geophysical studies, which lead finally to drilling wells. Because wells are a large part of the investment for geothermal direct heat, the geologic and geophysical studies are essential.

Although no one knows for sure the extent of the geothermal hot water resources in the United States, a survey conducted by the U.S. Geologic Survey in 1983 found that known low-temperature hot water resources could provide 41,000 thermal megawatts of heat for 30 years. That's the energy equivalent of more than 1188 trillion cubic feet (1 trillion cubic meters) of natural gas each year, or more than 60 times the amount used throughout the country in 1 year. The U.S. Geologic Survey also estimated that as-yet-undiscovered resources could raise the resource estimate by about 70 percent.

As opposed to direct heat systems, geothermal heat pumps can be used throughout the country. The only real requirement is enough soil in which to bury the heat-exchange pipes. Geothermal heat pumps have proved most popular in areas with large heating requirements, such as the Northeast and the northern Midwest, but they have been installed in almost every state in the nation.

Geothermal Electric Power

As explained in the section on geothermal direct use page 20, geothermal power draws on underground reservoirs of steam or hot water at temperatures greater than 93EC (200EF). Depending on the reservoir, power is generated using either dry steam, flash, or binary power plants.

"Dry steam" plants draw from an underground reservoir of steam. the only known examples in the United States are at The Geysers in northern California and Yellowstone National Park in Wyoming. Because Yellowstone is protected from geothermal development, the only dry steam plants in the country are at The Geysers. Dry steam plants are very simple: the steam is piped directly from the geothermal wells to the power plant, where the steam is fed to a turbine generator to produce power (see the solar thermal section, page 14, for a description of power plant technologies).

This dry steam geothermal power plant is located close to Brawley, California.

The power plants at The Geysers have a combined capacity of 900 megawatts, roughly equivalent to a large coal or nuclear plant. This huge capacity makes The Geysers the largest source of geothermal power in the world.

For hot water resources, the most widely used power plants are "flash steam" plants. When the water is hotter than 200EC (396EF), it is more than hot enough to boil, but the pressure underground prevents it from boiling. Flash steam plants take advantage of this by piping the pressurized hot water into a tank, where its pressure is suddenly lowered. The water rapidly changes to steam, that is, it "flashes" to steam. The steam is then routed to a turbine generator to produce power.

This dual flash geothermal plant provides power to the utility grid in Heber, California.

The final type of geothermal power plant is a "binary" plant, which is always used when the geothermal water is cooler than 200EC (396EF). However, a binary plant can also be used for higher temperature geothermal water. Binary plants get their name from the fact that they consist of two separate parts—one part of the plant only circulates geothermal water, and the other part only circulates another fluid. This other fluid is called a "working" fluid because it seems to do all the work.

The part of the plant that circulates geothermal water is very simple. Its purpose is just to pipe the hot water to a heat exchanger, in which the heat is used to vaporize the working fluid. After the geothermal water passes through the heat exchanger, it is relatively cool and is pumped back into the ground.

The working fluid part of the plant is a big closed loop. The working fluid, usually an organic liquid such as isobutane, is constantly circulating through this loop. In the heat exchanger, the working fluid absorbs the heat of the geothermal hot water and is turned to vapor. This vapor is then sent to a turbine generator to make electricity. The cool vapor coming out of the turbine is condensed to liquid, which is pumped back to the heat exchanger.

Binary plants are used for lower temperature geothermal water because the working fluid vaporizes at a lower temperature than does water, allowing the plant to run efficiently even though the geothermal water is relatively cool.

Injection of Geothermal Water

The source of water for geothermal reservoirs is primarily rainwater seeping down through the ground. If geothermal power plants draw water from the reservoir faster than it's replaced by rainwater, the reservoir could eventually start to be depleted, and the power production at the plants could slowly drop off.

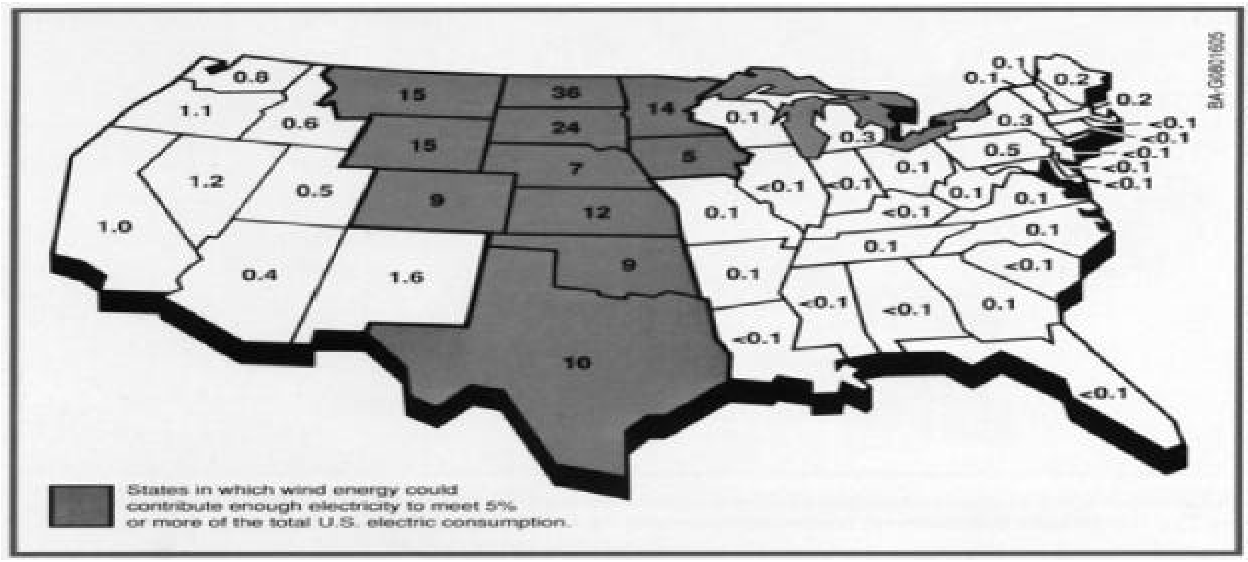
To avoid this problem, most power plants in the United States inject the used geothermal water back into the reservoir. This replenishes the reservoir and allows it to keep producing hot water or steam. Injecting the water also has environmental benefits because the geothermal water is often contaminated with small amounts of heavy metals and other impurities. Putting the water back where it came from helps to avoid the environmental problems associated with these impurities.

For dry steam plants, most of the steam is lost through the cooling towers, and only a small amount is condensed and returned to the reservoir. At The Geysers, concern about the long-term life of the reservoir has led to two new projects: one to condense more of the steam, increasing the amount of water returned to the reservoir, and another to pump water from another source and inject it into the reservoir. These projects should guarantee that The Geysers continues to produce power for many years to come.

The Geothermal Resource for Power Production

As discussed in the section about geothermal direct use, the geothermal resources in this country are immense, but they are often located in small, difficult-to-locate reservoirs. The accompanying map shows the general locations of known geothermal resources.

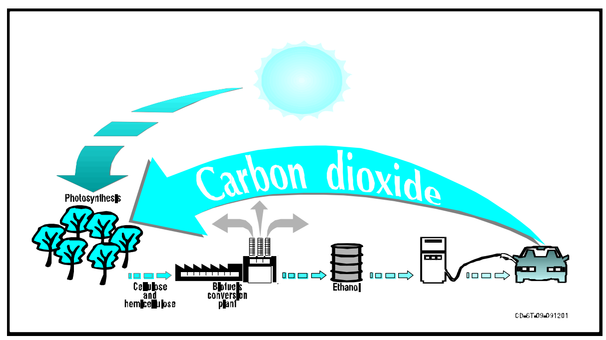
Included on this map are "geopressured" resources, which are geothermal hot water reservoirs that are under high pressure and are saturated with methane gas. These resources are located deep underground, so it does not pay to retrieve them only for their geothermal heat. The U.S. Department of Energy has developed a power plant that uses both the geothermal heat and the methane gas to produce electricity—a combination that makes the resource more attractive. The ideal plant would also use the mechanical energy trapped in the high-pressure water. As yet, geopressured resources are not being used commercially.



Biomass Energy from Plants and Trees

Biomass energy is the energy stored in plants and trees. Because plants and trees depend on sunlight to grow, biomass energy is really a form of solar energy. Biomass is one of the earliest energy sources used by human beings, because prehistoric people burned wood to cook food and to keep themselves warm. Wood is still the largest source of biomass energy, but modern facilities are also using corn, sugar cane residue, and other agricultural by-products. Municipal waste is also considered biomass, but we discuss it separately in the following section (page 29).

Biomass energy has environmental advantages in terms of emissions of carbon dioxide, a greenhouse gas. Although the burning of a tree or plant releases carbon dioxide, an equal amount of carbon dioxide is removed from the atmosphere when a new tree or plant grows. As long as the plants that are burned are replaced by growing new plants, the net emission of carbon dioxide is zero.



Biomass is also low in sulfur—it's less than 0.1 percent sulfur by weight. Because of this, biomass gives off very little sulfur dioxide, a major cause of acid rain, when burned. Sulfur dioxide is the reason many coal plants require scrubbers to cut their emissions.

Biomass can be used in three ways: burn it directly to generate heat and electricity, convert it to a gaseous fuel such as methane, or convert it to liquid fuels. These liquid fuels, also called "biofuels," include two forms of alcohol: ethanol and methanol.

Biomass Power

Wood is currently the largest source of biomass power. Although many people burn wood in their homes for heat, the largest users of wood for energy are the lumber and pulp and paper industries. These industries feed wood chips and scraps to their boilers as fuel. The boilers produce steam that is used directly in their manufacturing processes and for heat in their buildings. Many facilities also pipe the steam to a turbine generator for electric power production. With this combination of wood-fired steam and electric power, the lumber industry meets about three-quarters of its energy needs, and the pulp and paper industry meets about 55 percent of its energy needs.

James River pulp and paper mill where hybrid poplar is processed as an energy crop.

The facilities that produce electric power usually produce more than is needed on-site, so the excess power is sold to electric utilities. The Edison Electric Institute estimates that 6745 megawatts of non-utility wood-fired power plants were generating electricity in 1995—more than the equivalent of six large coal-fired plants.

Agricultural wastes are also burned to produce electricity, adding another 635 megawatts of biomass electric power. These power-generating wastes include bagasse (sugarcane residue), rice hulls, rice straw, nut shells, crop residues, and prunings from orchards and vineyards.

New wood-fired power plants may soon use advanced power plant technologies, now under development, that allow small trees to be burned whole. This saves the cost and energy of chopping up the wood. Such power plants would be supplied by tree farms that would grow fast-growing trees solely for their use as an energy crop.

Wood chips are used to power this electric power plant in Anderson, California.

Other sophisticated technologies for converting biomass into electricity are now being commercialized. One example is biomass "pyrolysis," which is the liquefication of biomass with heat. If biomass is heated in the absence of oxygen, it forms a liquid that can be used as a substitute for fuel oil. Some coal plants may use powdered coal mixed with liquefied biomass to meet new environmental regulations economically.

Perhaps the ultimate use of biomass for power production, now under development, is biomass gasification. Gasifiers use high temperatures to convert the biomass to a gas (a mixture of hydrogen, carbon monoxide, and methane), which is then used to fuel a gas turbine. A gas turbine is very much like a jet engine, except it turns an electric generator instead of propelling a jet. Because the gas turbines operate at very high efficiencies, the combination of a gasifier and a gas turbine will produce electricity more efficiently and more economically than do today's direct-burn plants. Their high efficiency allows these gasification plants to be built in places where the biomass resource is too limited to support one of today's direct-burn plants.

Biomass Fuels

Biomass has an advantage over other renewable energy resources (such as sunlight) because it can be converted directly into liquid fuels. This allows biomass energy to help supply the fuel needs of the transportation sector (cars, trucks, buses, airplanes, and trains), which uses nearly one-third of our nation's energy.

Currently, the most commonly used biomass fuel in the United States is ethanol, primarily produced from corn. Ethanol is the same alcohol found in beer, wine, and liquor. As a fuel, ethanol is usually used as an additive to gasoline, but cars could also be modified to run on pure ethanol. When used in its pure form, ethanol is usually "denatured" by adding about 5 percent gasoline, causing it to be poisonous and preventing people from drinking it.

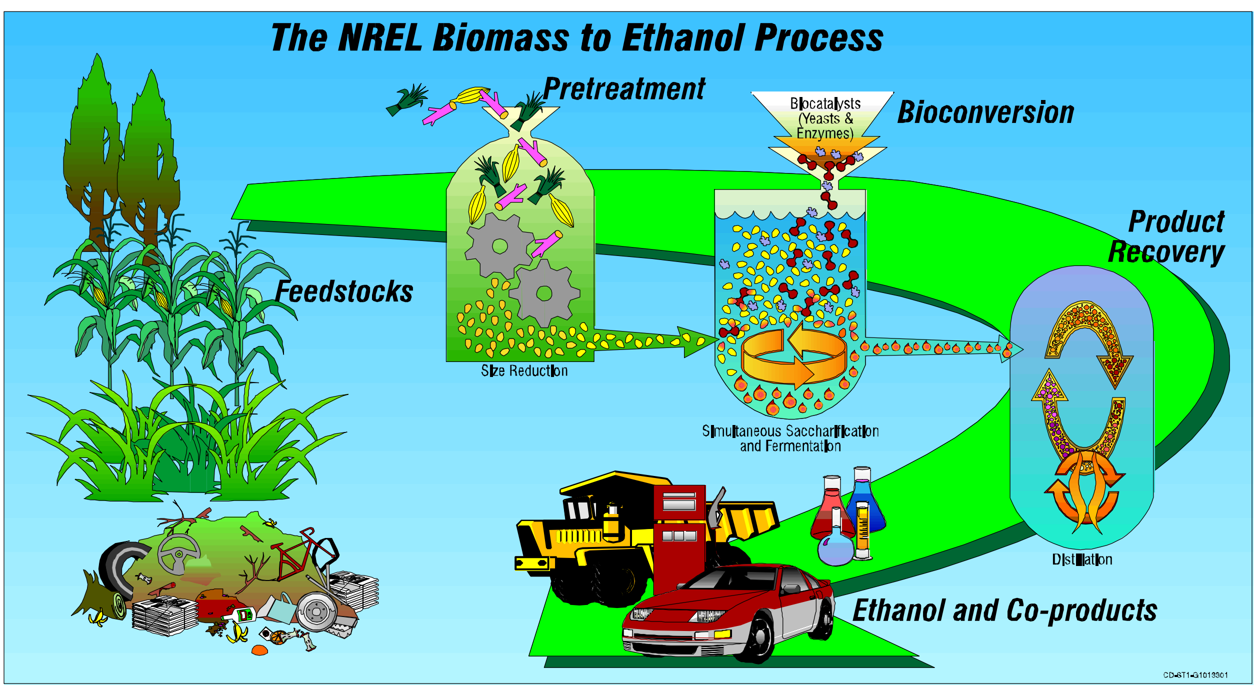
This 1996 Ford Taurus is a "flexible fuel" vehicle, which can run on either ethanol or standard gasoline.

When added to gasoline, ethanol cuts down on carbon monoxide and other smog-causing hydrocarbon emissions from cars. However, corn is expensive, and all the corn that could be grown in the United States would not produce enough ethanol to power all the cars. The challenge, then, is to produce ethanol or other fuels from other types of biomass.

As any home brewer knows, ethanol can be made easily by fermenting anything with a lot of carbohydrates (starches or sugars): barley, hops, corn, potatoes, and fruits. But the types of biomass that are cheapest and produce the most energy per acre are trees and grasses. However, both are made of fibers that are hard to convert to ethanol with traditional fermentation. The future of biomass fuels lies in new processes that break down these fibers to release their carbohydrates, which can then be converted to ethanol.

Many steps make up the process for producing ethanol from woody biomass. First, some sort of chopping or grinding machine would reduce the trees and grasses to small pieces. An acid treatment can also be used to partially break down the biomass. After this treatment, about one-third of the carbohydrates is separated out, mainly as a sugar called "xylose." Through new technology developed by the U.S. Department of Energy, this xylose can then be converted to ethanol in a separate process, using yeasts or other microbes, such as bacteria or fungi.

About two-thirds of the carbohydrates are left in the form of cellulose. Enzymes called "cellulases," produced from fungi or bacteria, are added to the cellulose to convert it into glucose. The glucose is then easily converted to ethanol by fermenting it with yeast.



Although this process involves many steps, it has been fine-tuned through much research to produce ethanol at roughly the same cost as ethanol produced from corn. To further reduce the costs, researchers are attempting to combine several of the steps, and are using biotechnology to improve the performance of the enzymes and microbes used in the process.

Small-scale versions of this process have been built, and although researchers are still examining ways to make the process more efficient and less expensive, it is already being scaled up. Industry is interested in using this process to make ethanol as a gasoline additive, and pilot plants are now being built and operated to test the process at larger scales. The intent is to use the information from the pilot plants to build a full-scale plant within the next few years.

Another possible fuel from biomass is methanol, commonly called wood alcohol. Methanol can be made by gasifying biomass and sending the hot gas through a tube packed with beads of a catalyst. A catalyst is a material—often a metal or ceramic—that helps a specific chemical reaction occur. In this case, the catalyst helps to convert the hot gas to methanol, which comes out the end of the tube. Similar methods can also be used to convert biomass into chemicals that can be used to make ethyl tertiary butyl ether (ETBE) or methyl tertiary butyl ether (MTBE), both of which are pollution-reducing additives for gasoline.

This bus in Nebraska runs on biodiesel fuel made from soybeans.

Diesel fuel can be replaced by a biomass fuel made from vegetable oils. In the United States, this "biodiesel" is now being commercially produced from soybean oil.

Any of the vegetable oils currently produced in the United States—soybean, corn, cottonseed, peanut, sunflower, or canola—could be used to produce biodiesel. Researchers are also developing algae to produce oils that can be used as biodiesel.

The Biomass Resource

The current biomass energy industry is fueled by forestry wastes, agricultural wastes, and excess corn production. But the processes now under development could greatly expand the use of biomass energy in the United States. If these technologies are successful, a new "energy industry" may spring up as a new breed of farms throughout the country—farms cultivating "energy crops" such as fast-growing trees or grasses.

These energy crops could revitalize farming and fortify U.S. energy independence. Currently, more than 50 million acres (20 million hectares) of agricultural land could be used to grow energy crops. Because much of this is cropland that is intentionally left idle, new energy crops will not cut into the land needed for forestry or food production.

This unused land has a great potential for energy production. For biomass power, the U.S. Department of Energy predicts that the power production could exceed 100,000 megawatts by the year 2030—the equivalent of 100 large coal plants. Although most existing biomass power plants use forest and agricultural wastes, future biomass power plants will rely on dedicated energy crops. Energy-crop farms near the power plants will serve as their fuel supply.

One restriction on biomass power plants is the cost of shipping the fuel to the plant. Most plant operators find that it doesn't pay to ship fuel more than 50 miles (80 kilometers). But because a 100-megawatt plant needs more than 100,000 acres (40,468 hectares) of land to support it, you might think that the entire surrounding area would have to start growing energy crops. In fact, 100,000 acres would be only 2 percent of the land within 50 miles of the plant.

Of course, several biomass power plants could be located in the same area. Because several power

Hybrid poplars, eucalyptus and switchgrass can all be grown and used as energy crops to produce biofuels.

Eucalyptus

Switchgrass

plants could draw on the same land for energy crops, the total land use for biomass power could be higher than 2 percent of the land. But even if as much as 7 percent of U.S. land were used to grow energy crops, they would still be considered secondary crops—too small to compete for land with any of the major agricultural crops. This means that there is plenty of room for biomass power plants in areas where energy crops can be grown.

In contrast to energy crops for biomass power, energy crops for biofuels *could* become a major crop. Currently, corn and other grains are used in the United States to produce more than 1 billion gallons (3.8 billion liters) of ethanol each year. This sounds like a lot, but even if this production were quadrupled, it would be only about 3 percent of the amount we need to fuel our cars.

Making ethanol from wood and grasses will help fill the gap. In the United States, agricultural and forestry wastes alone could produce more than 40 billion gallons (151 billion liters) of ethanol per year. Farm land that currently lies idle could be used to grow biomass, generating as much as 78 billion gallons (295 billion liters) of ethanol per year. And uncultivated fields could be converted to grow crops that will make as much as 120 billion gallons (454 billion liters) of ethanol per year. Using all this idle farm land and uncultivated land will provide new opportunities for farmers, and that means jobs and a boost to the economies of these agricultural areas.

The combination of all these sources of ethanol totals nearly 240 billion gallons (900 billion liters) of ethanol per year. Today's cars would burn ethanol about 50 percent faster than gasoline; that is, it takes 15 gallons of ethanol to replace 10 gallons of gasoline. That means that an annual production of 240 billion gallons of ethanol would replace about 160 billion gallons (606 billion liters) of gasoline each year. That's about 30 percent more than the 121 billion gallons (458 billion liters) of gasoline that are currently used each year. So we see that ethanol could fuel this nation's cars with plenty of room to grow.

To use ethanol even more efficiently, manufacturers have developed new car designs specifically to burn ethanol and other alternative fuels. Federal fleets and metropolitan transit agencies are now testing these new cars across the country, allowing researchers to gather real-world information about the cars' emissions, performance, reliability, and fuel economy. They even design some of these cars to switch easily between alternative fuels, like ethanol and methanol, and standard gasoline. That means the cars won't get stranded if they run out of ethanol far from an ethanol station.

Cars designed specifically to burn ethanol and methanol more efficiently will stretch the biomass supply even further. The most efficient new ethanol-fueled cars use only 12.5 gallons of ethanol to do the work of 10 gallons of gasoline. An annual production of 240 billion gallons of ethanol, then, would replace about 190 billion gallons (719 billion liters) of gasoline. That is roughly two-thirds more gasoline than is we use today.

The biomass resource looks equally good if it is used to produce methanol instead of ethanol. An estimated 2.7 billion tons (2.45 billion metric tons) of biomass could be converted into methanol each year. That is enough to produce about 456 billion gallons (1766 billion liters) of methanol each year. Modern engines designed to burn methanol use about 1.7 gallons of methanol for every gallon of gasoline burned by a gasoline engine. This means that methanol-powered cars could displace 268 billion gallons (1015 billion liters) of gasoline each year—more than twice the amount currently used.

Biomass could also easily supply the needs for ETBE and MTBE additives to gasoline. And biodiesel production from vegetable oils and algae could be used to make more than 50 percent of the diesel fuel used in the United States.

However, while we wait for these new biomass fuels to replace our gasoline supply, it is also good to know that U.S. auto companies are working to design cars that will burn less fuel. The "Big Three" auto manufacturers (General Motors, Chrysler, and Ford) and the U.S. Department of Energy are developing a "hybrid" car, which burns fuel but is designed primarily to run off of some type of energy storage device, such as a battery or flywheel (see page 35).

One example of a hybrid car is essentially an electric car, with an electric motor powered by batteries. To maintain the performance that we expect from our automobiles, a small gasoline engine provides extra power when needed. To make the car even more efficient, automotive designers are working to capture and convert the energy of braking the car to electricity, which recharges the battery. Such a hybrid car burns only one-third to one-half the gasoline that today's cars burn, with the same safety, comfort, and performance. Hybrid cars also emit less pollution.

Biomass Energy from Trash

Besides the biomass resources discussed in the previous section (plants and trees), another form of biomass is associated more with cities than farms: "municipal solid waste," or in plain language, trash. But what is trash to you may be fuel to someone else, because this municipal waste also has the potential to be a large energy source.

America's garbage can be turned into methane (natural gas) providing an alternative to landfill burial.

Municipal waste-to-energy plants generate steam and electric power by burning the trash and using its heat to generate steam, much like conventional power plants. The steam can be used for industrial processes or piped to a turbine generator to produce power. Municipal waste-to-energy plants currently generate 2450 megawatts of electricity, the equivalent of several large coal plants.

This landfill gas-to-electricity facility at a public landfill in Rhode Island produces as much as 12.3 megawatts of electricity, enough to serve 17,000 households.

Municipal waste may also be used in many of the processes now under development for biomass: biomass pyrolysis to form gasoline additives or a fuel-oil substitute, biomass gasification for use with a gas turbine, and biochemical conversion into ethanol. Municipal waste has the potential to produce 9.2 billion gallons (35 billion liters) of ethanol each year—enough to replace more than 6 billion gallons (23 billion liters) of gasoline.

There is also a way to use the energy trapped in waste that has already ended up in a landfill. The decay of food scraps and other organic materials in landfills produces a gas composed primarily of methane, a fuel that is the main component in natural gas. Wells can be drilled into the landfills to release this gas, and pipes from each well can carry the landfill gas to a central point where it can be filtered and cleaned. The gas can then be burned in a boiler to produce steam for industrial processes, or it can be used to generate electricity.

Whatever the use, burning methane provides environmental benefits, because the methane released from landfills is a pollutant that contributes to smog. To reduce this problem, more than 10 percent of the nation's 6000 landfills are expected to require gas collection systems to comply with new federal regulations on landfill gas emissions. Methane is also a potent greenhouse gas—21 times worse than carbon dioxide—so burning it to produce energy is an extremely effective way to help reduce greenhouse gas emissions.

We see, then, that producing power from landfill gas provides a double benefit— it burns the unwanted methane, and it produces useful electricity. Most landfill operators burn the gas in an engine that drives a small generator, but the operators of larger landfills use gas turbine power plants and also recover the heat of combustion for other uses. Selling the power helps pay for the cost of the landfill gas collection system. New federal tax credits, valid through the year 2007, are also encouraging landfill operators to use their landfill gas for power production. Currently, about 100 power plants in 27 states are generating more than 300 megawatts of electricity—roughly the equivalent of one coal plant.

The Resource for Municipal Solid Waste and Landfill Gas Recovery

Municipal waste is a large, and largely untapped, energy resource. The Environmental Protection Agency estimated that the United States generated 196 million tons (177 billion kilograms) of municipal waste in 1990. Of this waste, 67 percent was put in landfills, 17 percent was recovered for recycling and composting, and only about 16 percent was converted to energy.

Municipal waste is generated where people live—municipal waste and landfill resources are located in populated areas and near every large city. Most municipal waste-to-energy plants depend on the trash from several nearby towns and cities, as do most landfills. In general, this means that the power produced from municipal waste and landfill gas is available in the areas where it is needed most.

Unlike most energy resources, municipal waste is one source of energy that someone will collect, deliver to the plant, and pay to get rid of. This helps to cover the cost of the waste-to-energy plant, because the plant operator gets paid to receive the trash and also gets paid for the power the plant produces.

Municipal waste is also a unique resource in that every person in the country helps to create it. The box on page 3 shows how much electricity can be generated from the waste produced by the average person in the United States. It totals 270 kilowatt-hours of electricity, or enough to power a color television for 4 hours a day, every day of the year. Nationwide, the trash that currently goes to landfills could be used to generate more than 46 billion kilowatt-hours of electricity each year. It would take more than 21 million tons (19 billion kilograms) of coal to produce that much power.

Potentially, a large amount of power can be produced from landfill gas. The Environmental Protection Agency has estimated that landfills currently emit 16.5–35.3 billion pounds (7.5–16 billion kilograms) of methane each year. The new rules on controlling methane emissions should result in the collection of 15.4–22 billion pounds (7–10 billion kilograms) of methane each year. That has an energy value of about 13.7 billion kilowatt-hours per year: enough electricity to power more than 1 million homes.

For an example of the energy that can be produced from municipal waste, consider that the average person in the United States produces about 1500 pounds (about 680 kilograms) of solid waste each year. About 65 percent (0.65) of that can be burned, or about 975 pounds (440 kilograms):

$$1500 \text{ pounds total} \times 0.65 = 975 \text{ burnable pounds}$$

Burning this waste produces about 1.3 kilowatt-hours of heat per pound, for a total of 1285 kilowatt-hours of heat:

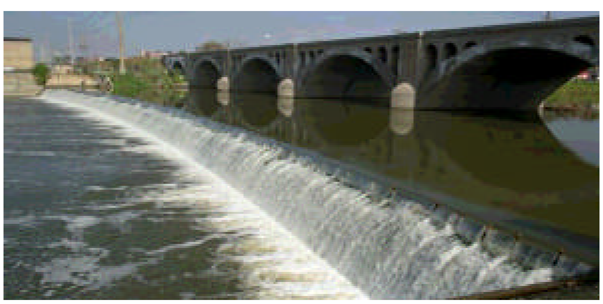
$$975 \text{ pounds} \times 1.3 \text{ kilowatt-hours of heat per pound} = 1285 \text{ kilowatt-hours of heat}$$

The heat from burning the waste can be converted into electricity with an efficiency of about 21 percent (0.21). Multiplying 1285 kilowatts by 0.21 yields an annual production of about 270 kilowatt-hours of electricity per person:

$$1285 \text{ kilowatt-hours of heat} \times 0.21 = 270 \text{ kilowatt-hours of electricity}$$

Hydropower

The energy of flowing water can be captured and turned into hydroelectric power, also called "hydropower." The most common form of hydropower uses a dam on a river to retain a large reservoir of water. Water released from the reservoir flows through a turbine and spins it, much like the old-fashioned water wheels were turned by the water flowing over them. The old water wheels were connected to mill stones, which slowly turned as they ground grain to flour; hydropower turbines are connected to generators, which spin rapidly as they produce electricity.



Hydroelectric facilities like this one generate about 10 percent of the nation's electricity.

Hydropower is actually a form of solar power, because the sun is constantly recylcing the world's water. The sun helps to evaporate water from lakes and oceans, and this evaporated water forms clouds that eventually cause rain or snow. The cycle is completed when the rain and the melted snow flow downhill in rivers and streams until they spill back into the lakes and oceans. Because hydropower uses the energy of these flowing rivers, it's actually tapping the energy of this vast global cycle of water.

Hydropower does not necessarily require a large dam. Some hydropower plants are built to operate with very little stored water, so they only need a small dike to channel the river water through the turbine. Sometimes, a portion of the river is diverted through a canal or pipe to the turbine, leaving the main part of the river undisturbed.

A totally different type of hydropower, called "pumped storage," uses a reservoir to store power—in a way, it's like a giant battery. The "battery" is charged by sending power from the power grid into the electric generators, which then turn backward and work as motors to spin the turbines backward. This causes the turbines to work as pumps, pumping water from a river or lower reservoir to an upper reservoir. To draw power from this "battery," the water is released from the upper reservoir back down to the river or lower reservoir. As it flows back down, it spins the turbines, which turn the electric generators, producing electricity.

These pumped storage plants are used to store energy when a utility produces more electricity than is needed; in turn, they produce electricity when the demand is high. Typically, pumped storage plants are about 70–80 percent efficient; that is, about 70–80 percent of the electricity used to pump the water up is returned when the water flows back down.

Pumped storage plants make sense because they save wear and tear on large utility power plants such as coal and nuclear plants. Many of these large utility power plants are designed to run only at full power, and reducing their power when the demand is low is impractical. Instead, the unneeded electricity they generate can be stored in a pumped storage plant.

Pumped storage plants also make it possible to meet high power demands without building new power plants. They serve as excellent emergency sources of power—like having fully charged batteries in your flashlight. Pumped storage plants can go from zero power to several thousand megawatts of power production in a matter of seconds.

Hydropower is currently the largest source of renewable power, generating about 10 percent of the nation's electricity—even more during periods of high electrical demand. Hydropower is also very inexpensive, and like most renewables, it doesn't produce any air pollution.

Hydropower Resources

Hydropower capacity is how much power all the hydropower plants would produce if they were all running full speed simultaneously. Of course, this never happens, but this map gives an idea of how many hydropower plants have been built.

For most technologies, instead of looking at capacity, we have looked at the resource—how big the capacity could eventually be. Unfortunately, it's very difficult to assess the resource for hydropower. That assessment would require studying every river in the country to find appropriate hydropower sites, and such a thorough assessment has not been done.

On the other hand, hydropower capacity can be expanded in some obvious ways. One way is to add hydropower equipment to existing dams. Of the 80,000 dams in the United States, only 2400 are used to generate power. Although many of the remaining 77,600 dams are unsuitable for hydropower, converting just a fraction of them to hydropower would add significant capacity. A recent study found that more than 15,000 megawatts of capacity could be added without building new dams. That's equal to about eight large coal or nuclear plants.

Another approach is to upgrade the existing hydropower facilities to make them more efficient. Many of the nation's hydropower plants were built in the 1930s and 1940s, and they use old, inefficient technology. New generator technologies are allowing hydropower plant owners to squeeze extra power out of the same amount of water. Just a 1 percent improvement in the efficiency of our country's hydropower plants could produce enough power for 283,000 households.

Finally, many rivers could hold small hydropower plants. These plants require only a small dam, or they could use existing flood-control or water-supply structures. They can provide enough power for a small town, with minimal environmental effects.

This small hydro facility in King Cove, Alaska went on line in December 1994 to service the remote 700-resident town.

Ocean Thermal Energy

The oceans can be considered the world's largest solar energy collector: nearly three-quarters of the Earth's surface is covered by oceans. Using even a minute fraction of the heat, or "thermal energy" trapped in oceans could power the world.

The sun's heating effect on the ocean causes the surface water to be much warmer than the cool deep ocean water. In many places, the surface water is about 35E–40EF hotter than the water at depths of a half mile or more. This temperature difference can be used to generate power in several ways: using closed-cycle systems, open-cycle systems, and hybrid systems.

Closed-cycle systems use the warm water near the ocean's surface to vaporize a fluid such as ammonia or freon. Both fluids—often called "working" fluids—have low boiling points. The warm water is pumped past coils

of tubing that carry the working fluid, causing the fluid to vaporize. The vapor is then sent through a turbine generator to produce electricity. Cool water from the ocean depths is used to condense the vapor back to fluid, and the fluid is reused. The fluid ends up recirculating through a large closed loop of piping—a closed cycle.

Open-cycle systems operate at pressures so low that warm seawater actually boils. The system sucks in warm seawater near the surface and rapidly lowers its pressure to make it boil. The steam passes through a turbine generator, producing electricity, and is then cooled and condensed by cool water from the ocean depths. The seawater isn't recycled in this system—warm seawater is sucked in and cool water comes out—so it forms an open cycle. This system has a big advantage: when the seawater boils, the salts and impurities are left behind, and the steam is essentially pure water. So the open-cycle system produces power and results in distilled potable water—a valuable commodity in some parts of the world.

Finally, hybrid systems combine both closed-cycle and open-cycle systems. Hybrid systems still use a closed cycle to produce power, but instead of just using warm seawater to vaporize the fluid, the warm seawater is first exposed to low pressure to make it boil, just as in the open cycle. The steam then condenses on the coils of tubing that carry the working fluid. The steam cools and condenses back to water, giving up its heat to the working fluid, which is vaporized. As in the closed cycle, the working fluid vapor is piped through a turbine generator to produce power. Hybrid systems have an extra advantage because the condensed steam forms distilled potable water.

The only ocean thermal power plant to ever operate was a prototype open-cycle plant in Hawaii. Called the Net Power Producing Experiment, the plant was designed to produce 210 kilowatts of electricity, but it actually generated as much as 255 kilowatts of electricty— 20 percent more than design. Because the plant used 152 kilowatts to keep running, its net power production was as high as 103 kilowatts.

Ocean thermal energy conversion technology in Hawaii.

Located on shore, the plant used warm surface water from near the shore and cold water pumped up from a depth of 2200 feet (670 meters). The vacuum tank, where the warm seawater was boiled, was a concrete structure 25 feet (7.6 meters) in diameter and 31 feet (9.4 meters) high. The plant operated from 1992 to 1995.

The Resource for Ocean Thermal Energy

Because ocean thermal energy systems rely on the difference in temperature between the surface and the deep ocean, the resource is greatest in areas where the surface is heated the most—in the tropics. Large resources exist in the Gulf of Mexico and in the central Pacific, Indian, and Atlantic oceans.

Unlike most renewable resources, the ocean thermal resource is constant, with only seasonal variations in the available energy. This is an advantage to electric utilities, which usually prefer a power source that can be tapped whenever it's needed.

Ocean thermal energy plants could be located offshore, just like offshore oil rigs, or they could float far out to sea. The electricity could be sent to shore by undersea cable, or it could be used to support offshore industries. For instance, a farm for growing ocean fish and a process to reclaim valuable minerals from seawater could both be located at sea and use ocean energy as their power source. Ocean energy could also be used to produce chemicals that can be used as fuels on the mainland, such as hydrogen or methanol.

Ocean thermal energy plants could also be located on shorelines that are near thermal resources. Warm water would be drawn directly off the surface near shore, and the cold seawater would be drawn from a pipe that followed the ocean bottom away from shore until it reached the lower levels of cold water.

The worldwide potential for generating electricity from ocean thermal energy has been estimated at 2 million megawatts, roughly the equivalent of 1000 large coal or nuclear plants. This estimate is probably unrealistically large, because it does not exclude areas that may be inappropriate for power production (such as sensitive shorelines).

Ocean Mechanical Energy—Tides and Waves

Ocean mechanical energy—energy from the tides and the waves—is very different from ocean thermal energy. Tides and waves are caused by different phenomena than those resulting in ocean thermal energy. And tides and waves are intermittent sources of energy; ocean thermal energy is relatively constant. Also, unlike the power plant cycles of ocean thermal energy technology, the means of converting tides and waves to electricity all involve mechanical devices like buoys, dams, channels, and turbines.

The energy in the movement of tides and waves can be converted to electricity.

Tidal Energy

Tides are driven by the gravitational pull of the moon and, to a lesser degree, the sun. The shape of tidal basins and the way they are connected to the ocean causes great differences in tides throughout the world. These local effects cause some of the more extreme tides. For instance, the outlet of the Rance River in France experiences high tides that are 42 feet (13 meters) above low tide.

Tidal energy is relatively simple to capture and convert to electricity. Tidal power systems depend on a large wall or "breakwater" that separates a harbor from the ocean. As the tide swells into the harbor, the breakwater holds back the ocean and forces the water to pass through the turbines, generating electricity. It works similarly to using a dam to make a river flow through a hydropower plant. As the tide lets out, the water is trapped in the harbor and is again forced to pass through the turbines.

The largest tidal energy plant is a 240-megawatt plant in France, in the outlet of the Rance River on the coast of Brittany. Built in 1967, the plant uses a half-mile (750-meter) barrier to enclose a harbor area of 8 square miles (22 square kilometers). Much smaller tidal power plants are located in Canada, in Russia, and at several locations in the People's Republic of China.

Wave Energy

Ocean waves are driven by winds, by the same forces that cause tides, and occasionally by earthquakes. Winds are driven partly by the Earth's rotation, but mainly by temperature differences caused by sunshine. So the ultimate driving forces for waves include a full spectrum of natural forces: the sun, the gravitational pull of the moon and sun, the rotation of the Earth, and the energy within the Earth.

Various approaches have been developed for capturing wave power. One well-known technology, the "Salter duck," uses many floating wing-shaped flaps that are mounted on a pivot. As a wave passes by the flaps, they pivot up and down, driving hydraulic pumps. The pumps pressurize oil, and the oil pressure is used to turn a generator to produce electricity. Invented by Stephen Salter, the Salter duck is named for the way the flaps bob in the waves.

The largest operating wave-powered plant was built in 1985 at the town of Toftestallen on the North Sea coast of Norway. A 350-kilowatt plant there uses a "tapered channel" to produce power by funneling the waves into a reservoir. The waves are caught in a channel that narrows and rises as it nears the shore. The waves rise about 10 feet (3 meters) above sea level before they spill over into the reservoir. As in a hydropower plant, the water passes out of the reservoir and back into the ocean through a turbine, generating electricity. The Toftestallen plant produces as much power as a small coal- or oil-fired plant.

Yet another technology is the "oscillating water column" system, which uses a box-shaped or cylindrical container that either floats on the water or is permanently mounted to the shore. Either way, the bottom of the container is below sea level and is open, so the container is partially flooded with seawater.

As waves pass the container, they force the water level higher, compressing the air in the container. This compressed air is used to turn a turbine generator before the air is let out through slots in the container. Once the wave passes, the drop in water level sucks air into the container and again turns the turbine generator. Several baffles and one-way flaps keep the air flowing in the same direction through the turbine, whether the air is rushing into or out of the container.

A 500-kilowatt oscillating water column system operated at Toftestallen for 5 years, and three smaller plants have also been built—two in Japan and one in the United Kingdom.

The Resource for Tidal and Wave Energy

The worldwide potential for generating electricity from tides has been estimated at about 30 billion watts—roughly the equivalent of 15 large coal or nuclear plants. But this estimate doesn't exclude any areas that may be unfavorable for power development, such as sensitive shorelines. It also doesn't take into account the fact that tidal power depends heavily on properly siting the development.

Despite these restrictions, it is clear that tidal power has the potential to generate large amounts of energy. The large scale of the French plant on the Brittany coast (240 megawatts) provides some indication of the potential for tidal power technology.

For wave power, the worldwide potential for generating electricity has been estimated at about 2.7 trillion watts. That is more than four times the electrical generating capacity of all the power plants in the United States. Again, this estimate does not exclude areas that may be unsuitable for development, so it is unrealistically large.

Like tidal power, wave power depends on finding an appropriate location to build a power plant. In some locations, the average amount of wave energy hitting the shore is about 5 kilowatts per meter. In other words, every meter of shoreline receives enough wave energy to power two or three houses, if all the energy could be captured and used.

Energy Storage

Wind and solar energy are harder to use than other energy sources because they are intermittent—both the wind and sun come and go with the weather, and, of course, the sun is gone all night long. For stand-alone applications—such as using a wind turbine to power a home, or using photovoltaics to power a light—some method of energy storage is needed.

This large bank of batteries stores the sun's energy collected by a PV system.

Batteries are the most common form of energy storage. A simple electronic system can control the power flow to charge the battery when possible, to draw from the power source (for instance, the PV cell) when possible, and to draw from the battery when necessary. Other energy storage systems include superconducting magnetic energy storage, flywheels, and hydrogen. Pumped-storage hydropower, another energy storage technology, is discussed separately in the hydropower section, page 31.

Battery Energy Storage

The trick to battery storage is to develop small, inexpensive batteries that last a long time and that charge and discharge without losing much energy.

The most common battery used today is the lead-acid battery, the same kind of battery that starts your car. Lead-acid battery systems are about 76 percent efficient—if you use 100 kilowatt-hours charging them, you'll get 76 kilowatt-hours of electricity in return.

But one disadvantage of lead-acid batteries is that they can't be completely discharged without drastically shortening their useful life. To avoid this problem, lead-acid batteries are usually only discharged down to about 20 percent of their storage capacity.

Advanced sodium-sulfur batteries are now being developed that will achieve the same efficiency but will last longer, are smaller, and can be completely discharged without shortening their life. Because sodium-sulfur batteries use only one-quarter the space needed for lead-acid batteries, they can be housed in a smaller building. They will also cost less and will have a longer service life than lead-acid batteries.

Both lead-acid and sodium-sulfur batteries also have a place in utility power systems. A battery system can be used along with a grid-connected wind plant or PV system to help match the energy supply to the demand. Battery systems can also smooth out short-term power fluctuations caused by clouds or variable winds.

This sodium/sulfur battery is being developed for utility applications.

Battery systems have other advantages for utilities. Utilities can locate battery storage systems throughout their power grid, to store energy when the power demand is low and deliver energy when the demand is high. Meanwhile, the utility can transmit a constant amount of power through its large power transmission lines. Battery systems also have a number of other benefits for utilities in terms improving the reliability and quality of power delivered to customers.

Batteries are also used in electric vehicles, which depend on very efficient batteries to produce the most amount of electricity from each charging. Of course, low weight, small size, and low cost are also important needs for electric car batteries.

Superconductors for Magnetic Energy Storage and Flywheels

Superconducting magnetic energy storage is another storage technology under development. "Superconductors" are metals or ceramics that conduct electricity without any resistance when cooled to extremely low temperatures. If a current is circulated in a loop of superconducting wire, the current will continue to circulate for a long time. In contrast, a normal piece of wire would quickly heat up because of resistance, and the current would dwindle to nothing.

This is a prototype of an alternating current (ac) high-temperature superconductive motor.

This is exactly the principle used by superconducting magnetic energy storage. The electrical current from the renewable energy source is fed into a loop of superconductor, and it stays trapped in that loop until it's needed. These devices can store large amounts of electricity at efficiencies greater than 90 percent and release it extremely quickly—both properties make this an attractive energy storage method for renewable energy.

Superconductors, however, need extremely low temperatures to work. Liquid helium is required to keep the superconductors cool, and that adds to the cost of energy storage. A new class of materials called "high-temperature superconductors" can offer a solution. These materials still need to be kept fairly cool, but liquid nitrogen cools them effectively, and it is much cheaper than liquid helium. The challenge for researchers is to use high-temperature superconductors to make loops of cable that will carry high currents. Using high-temperature superconductors for magnetic energy storage is expected to make the technology much less expensive and more practical.

Energy can also be stored using flywheels, which are simply thin disks that are spun at very high rates of revolutions per minute. The flywheels are designed to minimize friction in every way possible, so their momentum keeps them spinning for long periods of time. A motor/generator puts energy into the flywheel when the flywheel is spun up to speed, and to extract the energy, the flywheel is slowed by using it to spin the generator, producing electricity. In effect, the flywheel is a mechanical battery.

The key to making flywheels work is to keep the friction on the flywheel as low as possible. One of the major sources of friction in any wheel is the bearing, as you know if your car's wheel bearings have ever gone bad. To keep flywheels nearly frictionless, researchers are developing a "superconducting magnetic bearing" for flywheels. This bearing is based on the fact that a magnet placed near a superconductor will be repelled by it. In fact, a magnet will actually float above a superconductor. The flywheel bearing takes advantage of this effect by mounting the flywheel shaft to a magnetic bearing, which floats above a superconducting bearing. Because the parts don't actually touch, the bearing has very low friction.

Both superconducting magnetic energy storage systems and flywheels are highly efficient energy-storage technologies, with efficiencies greater than 90 percent. They are also expected to have long lifetimes, making them ideal for utilities, which typically use 30-year financing to fund projects. It's the same as taking a 30-year mortgage on your house—you want the house to last at least as long as the mortgage. In the same way, utilities usually need their investments to last at least 30 years, and both superconducting magnetic energy storage and flywheels are expected to meet this need.

Hydrogen

Hydrogen is another way to store renewable energy, but it offers unique advantages in that it potentially can store *and* transport renewable energy. In other words, you can use renewable energy to make hydrogen, then send the hydrogen somewhere else and use it.

Hydrogen can be made simply by passing electricity through water, a process known as "electrolysis." When an electrical current is passed through water, it breaks down into its component parts: hydrogen and oxygen. Two electrodes—a positive and a negative electrode—are inserted into the water. When the current is turned on, hydrogen bubbles from the negative electrode, and oxygen bubbles from the positive electrode. The hydrogen can then be collected and stored.

Hydrogen generated from renewable energy sources offers great environmental benefits. Generated from environmentally clean energy sources, hydrogen can then be cleanly converted back to electricity using a "fuel cell." Fuel cells work like electrolysis in reverse, combining hydrogen and oxygen to make water while producing electricity. The only exhaust from fuel cells, which are the main source of power on the space shuttle, is water vapor.

As an illustration of rapid technology advancement in proton-exchange membrane fuel cell technology, the cell on the left is a previous generation and can generate 5kW of power; the cell on the right is about the same size, but can generate 13kW of electricity. Each cell can fit within the engine compartment of a diesel bus.

Hydrogen-powered cars, trucks, and buses would have essentially no emissions and would relieve the smog problems in many U.S. cities. The vehicles would actually be propelled by electric motors, supplied with electricity from a fuel cell.

Because hydrogen also burns cleanly in air to form water vapor, it could fuel clean-burning airplanes. Finally, it could be mixed with other fuels and burned to reduce emissions from power plants and boilers.

A Vision of the Future

Image a future in which your house supplies most of its own power. Its passive solar design heats and lights most of your home, and a solar hot water system heats most of your water. Maybe you even have a solar-powered air conditioner. And the PV arrays that function as your roof and walls provide much of your electrical needs.

Okay, maybe your house doesn't have solar cooling. Maybe you have a geothermal heat pump for heating and cooling instead. And if you live in the city, maybe you're hooked up to the town's geothermal heating system.

Your car might be fueled with ethanol or methanol. Then again, you may have chosen an electric car instead, especially if the parking lot at work features PV-powered recharging stations. Your electric car may even use a hydrogen-powered fuel cell to boost its performance.

Of course, you'll still need to buy some electricity—your home can't do it all. But indirectly, your home even contributes to generating the electricity you buy. Every time you take out the trash, you make a small contribution to your town's power supply.

Still, that doesn't supply enough power, and you can't help but be reminded of that as you drive out of town, past the old landfill. The power plant there is still turning methane into power, finding some benefit in yesterday's trash.

You head out onto the great plains, passing through a vast expanse of windfarms. You look at the crops growing under the wind turbines and wonder what they are. Could they be energy crops—perhaps sweet sorghum or switchgrass? And beyond the windfarm are rows of trees—is that just a tree farm, or are those quick-growing trees for a biomass power plant?

As you cross the desert, those distinctive towers of the central-receiver solar power plants are unmistakable. But that field of parabolic trough mirrors—is that a power plant, or is it just supplying heat for the nearby industrial facility?

What about that building with a cooling tower next to it? It might just be an industry, but it could also be a geothermal power plant—it's hard to tell the difference. Well, there seem to be some pretty big electrical wires running away from it; it must be a power plant.

Now, this village in the middle of nowhere seems pretty new. The lack of power lines and the big dish/engine system at the edge of town give it away as one of those solar settlements. It's hard to say where the residents hid their energy storage system.

As you cross this bridge across the old hydropower plant, you realize that this is one thing your grandfather would still recognize. Of course, it has been refurbished to put out more electricity with the same amount of water. Grandpa would never know the difference by looking, though.

Finally, you arrive at the shore. A wave energy plant is nestled in the cliff below you, but only the electrical wires give away its presence. In the harbor on your left, the tidal power plant is still letting out the water from the high tide. And out there on the horizon, you can just barely see the top of that ocean thermal energy plant sticking up above the ocean. It must use an undersea cable to send the power back to shore.

Is this all just a dream? Will this vision ever come to pass? Maybe, maybe not. All the parts of this vision are already here today, at least as prototypes, and most of these technologies are already commercialized. The difference between today and this vision of tomorrow is mainly a matter of awareness and economics. Yet many renewable energy technologies are already cost effective, and technological advances are cutting their costs every day.

Certainly, not all parts of this vision will come to pass. Some technologies will prove more useful than others. Every technology has some drawbacks that must be considered when the United States makes its energy choices. But the many benefits of renewable energy technologies—environmental cleanliness, energy efficiency, long-term sustainability, and energy independence—indicate that they will have a prominent place in our country's future.

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